TRANSACTIONS

American Society for Steel Treating

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The object of the Society shall be to promote the arts and sciences connected with either the manufacture or treatment of metals, or both.—Constitution A. S. S. T., Art. II.

THE SPRING SECTIONAL MEETING AT HARTFORD

THE Spring Sectional Meeting of the Society, held in Hartford, Connecticut, on May 20 and 21, 1926, was a decided success, as evidenced by the number of members in attendance, the excellence of the papers presented and the interest and enthusiasm expressed in the discussion which followed their presentation. This was the eighth sectional meeting of the Society and was exceptionally well conducted under the auspices of the Hartford Chapter.

Headquarters were at the Hotel Bond, where the banquet and two of the technical sessions were held.

Board of Directors Meet

The Board of Directors of the Society held an all-day executive session on Wednesday, May 19, the entire board being present. At this session a number of important matters were presented for consideration and passed upon. The minutes of this meeting will be published in full in the July issue of TRANSACTIONS. A few of the important and interesting matters acted upon are as follows: Announcement at the banquet, by President R. M. Bird, of the passing of a resolution that the Society extend its activities to include matters of interest and importance in the field of nonferrous metallurgy, especially pertaining to those alloys which are heat treated. Also that student groups (junior members) might be sponsored by local chapters or by authority of the Board of Directors.

The first group was organized May 10, 1926, at Case School of Applied Science, under the leadership of, and sponsored by, the Cleveland Chapter, and was officially recognized by this action. The Cleveland Chapter will provide four technical meetings during the ensuing year for the especial benefit of the Case Group.

It was also resolved that the national society shall be so organized as to assume all of the responsibilities and make all the arrangements and plans for conventions, to relieve the local chapter of the responsibilities and extensive work; the local chapter to function only in an advisory capacity.

The Board decided to hold the 1927 convention at Detroit, and the next winter sectional meeting in January, 1927, at Washington, D. C.

It was also decided that the office of assistant secretary be created.

Other questions of importance were taken up and voted upon dealing principally with matters pertaining to the Chicago Convention.

According to the custom heretofore established, the "Early Birds'" dinner was held directly after the adjournment of the directors' meeting. More than 80 members and guests motored to the Farmington Country Club, Farmington, Connecticut, to attend this dinner, which was a delightful affair, resulting in a very pleasant evening for all.

On Thursday, May 20, at 8:30 a. m., 400 members and guests registered as in attendance. Immediately following this, the morning session began. B. S. Lewis, chairman of the Hartford Chapter, welcomed the visiting members of the American Society for Steel Treating and their guests on behalf of the Hartford Chapter. He introduced Mayor Stevens of Hartford, who gave an address of welcome. President R. M. Bird responded to Mr. Stevens' cordial welcome.

B. S. Lewis then turned the meeting over to F. P. Gilligan, past president of the Society, who acted as chairman of the technical session.

The first paper scheduled, entitled, "*Recrystallization Temperatures of Cold-Rolled Electrolytic Iron and Open-Hearth Steel Strip,*" was read by Dr. H. S. Rawdon, Bureau of Standards, in the absence of J. R. Freeman, Jr., the author.

This paper sets forth the results of a study of the respective temperatures of recrystallization of electrolytic iron strip and open-hearth steel strip, specially selected for deep drawing operations. It also sets forth the result of tensile tests and microstructural studies of strip given different amounts of work by cold rolling and annealed at progressively increasing temperatures.

The author is of the opinion that tests show that electrolytic iron would probably be a somewhat superior material for deep drawing operations.

J. S. Vanick presented "*Factors Affecting the Machinability of Alloy Steels.*" This paper was written jointly by J. S. Vanick and T. H. Wickenden of the International Nickel Company of New York. It is a report of considerable investigation by the authors on this subject and deals mostly with the smooth finish machining of low-carbon, plain and alloy steels. Tests were conducted for the purpose of correlating the finishing cuts with the vast amount of data available upon roughing cuts and breakdown tests of tools. For this purpose a ¼-inch wide round nose tool, shaped to the 14-degree side slope, 8-degree back slope, and 6-degree clearance angles, recommended in Taylor's original work, was used for a series of cuts ranging from 0.015 to 0.090-inch in depth and 0.015 to 0.060-inch in feed. The circular disk method of varying the speed was used by starting the tool on its cut at the periphery of a 10-inch diameter disk, moving at a fixed speed, and thereby obtaining a speed variation from surface to center of the face. By this method the finish on the disk would change from a smooth to rough finish at certain critical speeds, the change being complete with a cutting speed change of 10 to 15 feet per minute. In general, at a still lower speed the finish would again change from rough to smooth. It was found that this critical area of rough finish and its corresponding cutting speed would vary with the depth of cut, the feed, the hardness of the material, and the cutting angle.

An interesting discussion followed each of these papers.

The afternoon was devoted to plant inspection trips; a wide choice being available, including: Colt's Armory, Hartford Rubber Works, Billings and Spencer, Pratt and Whitney Company, Royal Typewriter Company, Underwood Typewriter Company, Union Drawn Steel Company, and others.

The evening session was ushered in by the banquet, which was attended by 350 members and guests, the largest ever held at a sectional meeting.

S. M. Stone, president of the Colt's Patent Fire Arms Manufacturing Company, acted as toastmaster. The address of welcome was given by B. S. Lewis of Stanley works, and chairman

of the Hartford Chapter, to which R. M. Bird, national president of the Society, responded with "Our Society."

E. P. Root, president of the New Haven Clock Company, gave a most interesting talk on "Invention and Immigration," in which he stressed the great need for imagination in industry and pointed out how imagination leads the way to better things, and in a very simple and interesting manner brought out the fascinating romance of clock making.

Man is putting his creative force into action—harnessing it, so to speak—making it work for him while he is about some new thing. Inventions, like good habits, enlarge life and make more experiences possible. All immigrants have the faculty of imagination—vision. They see greater possibilities in a new and progressive country. It is this faculty which makes men brave unknown dangers and privations for a possible and ultimate better future. Imagination leads the way. It makes all things possible and overcomes all obstacles. It is the only sure-enough thing in the world. Intangible, abstract, elusive, yet it has made life what it is today and is constantly improving man. More and more is man getting in tune with the Infinite, for as man progresses Nature reveals all her powers and grandeur to him. He is the greatest artist who expresses the most joy in his work, for art is doing a thing in the best and simplest way.

Romance in industry, like the four-leafed clover, may be hard to find, but it is surely worth looking for. Our faith, that the four-leafed clover will bring good luck to the finder, so our faith in our work will be the greatest happiness a man can find on this earth.

National Director, F. G. Hughes, vice-president of the New Departure Manufacturing Company, Bristol, Connecticut, spoke at considerable length regarding the industries of New England, and pointed out how these industries are at the present time undergoing a change. Many industries which formerly flourished in New England have gone elsewhere. But the progressive New Englanders are awake to the situation and are making every effort to again place New England in the foremost ranks in the manufacturing field. In this activity the metallurgist and steel treater are playing no small rôle. This was demonstrated by those who had the privilege of visiting the many plants in and about Hartford which were open to the inspection of the members of the

American Society for Steel Treating.

Messrs. F. P. Gilligan, A. H. d'Arcambal and W. H. Eisenman were called upon by the toastmaster and responded with short talks of an informal nature.

Music was furnished by the Colonial Male Quartet and Si Yaffe's String Quartet.

On Friday, May 21, at 9:30 a. m., the second technical session was held in the Ball Room of the Hotel Bond, with A. H. d'Arcambal, metallurgist of the Pratt and Whitney Company, Hartford, in the chair. The first paper presented at this meeting was: "*Behavior of Carbon in a High-Chromium Rustless Iron,*" by Marcus A. Grossmann, metallurgist, United Alloy Steel Company of Canton, Ohio.

The author sets forth in his paper the characteristics of rustless iron of the high chromium type. His investigations show that up to 1800 degrees Fahr. the mechanical properties remained practically the same for different heating temperatures, but at 1800 degrees Fahr. a new set of mechanical properties is developed. It loses sharply in ductility without gaining greatly in hardness. It was observed that the material in the hot-rolled or annealed condition consisted of grains of alpha iron, with groups of precipitated carbides. When the metal was heated to above 1800 degrees Fahr., the carbide areas became austenitic, and upon quenching became martensitic.

The second paper, entitled, "*Forging by the Upset Process,*" was presented by J. C. Kielman, of the New Departure Manufacturing Company, Bristol, Connecticut.

The author gave a clear and interesting description and by means of numerous slides showed in detail the use of high-carbon chromium steel from its delivery at the plant to the finished forgings. The peculiarities of the steel and the method of forging were brought out. The problems encountered and the importance of the heat treatment of the tools were emphasized.

An interesting discussion followed the presentation of these papers.

In the afternoon interesting plant inspections were made by the members and their guests at the following plants: International Silver Laboratory at Meriden, New Departure Ball Bearing Plant at Bristol, and several others, which were selected by choice.

At the evening technical session, held in the meeting room of the Hartford Electric Illuminating Co., S. P. Rockwell acted as chairman. Two papers were presented: One on "*Stainless Iron*," by Norman L. Mochel, of the Westinghouse Electric and Manufacturing Company, Philadelphia, and the other on the "*Heat Treatment of Die-Blocks*," by A. J. Porter, Jr., sales manager of the Heppenstall Forge Company, Bridgeport, Connecticut.

Mr. Mochel's paper is the result of an extensive and comprehensive study of iron-chromium alloys from many points of view, including tensile strength, impact resistance, microscopic structure and degree of corrosion resistance.

This was a study of the physical properties of iron-chromium alloys, ranging in content from 10 to 19 per cent chromium, with a carbon content of approximately 0.12 per cent. Most of these alloys do not usually require heat treatment for the purpose of obtaining corrosion resistant properties. Many photomicrographs and physical properties' charts were exhibited by means of the stereopticon.

Mr. Porter's paper was primarily concerned with drop forge die-blocks, with especial reference to their heat treatment in the drop forge shop. The author reviewed the development of the drop forging industry and the development of the die-block which, he says, had to be perfected to meet the demands placed upon it. The diversification of this product is wide, both in utility and size, ranging from a scissor forging weighing a few ounces to the rear axle housing of an automobile truck, weighing several hundred pounds. The writer continued in an interesting manner to outline the various steps and pointed out the precautions to be observed in the heat treatment of die-blocks. After the discussion of these papers the meeting adjourned.

The schedule for Saturday, May 22, consisted of special plant inspection trips, as requested by members who desired them.

All of the papers which were presented at this sectional meeting will be published in future issues of TRANSACTIONS.

Members and officers of the Hartford Chapter are to be congratulated for the preparation of a most interesting, instructive, and entertaining sectional meeting. The details of arrangements were extensive and there was not a flaw in the efficient manner in which all of the events were carried through. On behalf of the Society, the members and guests present, we at this time wish to

express to the Hartford Chapter our sincere appreciation of their hospitality and to thank them most cordially for the many kindnesses and attentions which they extended to their guests.

STUDENT GROUP AT CASE SCHOOL OF APPLIED SCIENCE

ONE of the most important services which the American Society for Steel Treating can render is cooperation with students in metallurgy and metallurgical engineering. Such cooperation may take a number of forms; for instance, students may be invited to attend meetings of the local chapter, leading up to junior membership in the Society. This membership makes available to the young metallurgist at very low cost (the membership fee is $2.50) all the printed matter and other benefits of the Society, except the privilege of holding office or voting. Students may attend national conventions and sectional meetings when they are not too far away. One of the new services to students is the formation of school groups for the promotion of more personal contact with members of the local chapter. The first of these is the Case Group, recently established, in the Department of Metallurgical and Mining Engineering, Case School of Applied Science, Cleveland. The first meeting was held on May 10, in the Metallurgical Laboratory of the school. W. P. Sykes, Case, 1916, newly elected chairman of the Cleveland Chapter, gave an interesting talk on the iron-tungsten alloys which he has been investigating. About 20 students and three members of the teaching staff were present. The students unanimously voted to form a Case Group, and the following men were elected as officers for the coming year:

President, C. H. Junge, '27; secretary, J. M. Byrns, '27.

It is planned to hold four meetings during the coming season. Members of the American Society for Steel Treating will be selected as speakers.

The Department of Metallurgy at Case School had the honor of being the first school department to become a sustaining member of the Society. It now has the honor of being the first to organize a student group. *H. M. Boylston.*

OUR APPRECIATION

THE Canadian Machinery and Manufacturing News, in the issues of May 13, 20 and 27, published in the interests of

the Toronto Chapter of the American Society for Steel Treating, three articles dealing with the interesting question, "What is Steel?" and gave some of the opinions held by Dr. J. A. Mathews on this subject.

We are very proud of our Toronto Chapter and wish to extend to the Canadian Machinery and Manufacturing News our appreciation of their cooperation in stimulating interest and enthusiasm in the work of the American Society for Steel Treating in that chapter. We wish the Toronto Chapter collectively and individually a brilliant future.

On May 28, G. A. Richardson, manager of the technical publicity department of the Bethlehem Steel Corporation, was scheduled to give a paper, entitled, "Steel, the Giant Industry." The report of this meeting will be of interest to all of our readers and we hope that it will be received for publication in the July issue of TRANSACTIONS.

It is indeed gratifying to know that in this age of materialism there are those who recognize and appreciate the unselfish endeavors of a group of individuals who are happy in the giving of service for the benefit, comfort, happiness and well-being of their fellow men.

THIS issue of TRANSACTIONS completes Volume IX which covers the period from January, 1926, through June, 1926. Volume X will include the period from July, 1926, through December, 1926. The index for Volume IX is now ready and may be secured upon request.

Those desiring to have their loose copies of Volume IX bound in accordance with the style used in binding Volumes I-VIII inclusive, may do so by forwarding them to the executive offices of the Society, 4600 Prospect Avenue, Cleveland, together with $2.00, and they will be bound and returned promptly.

Future Meetings

ANNUAL CONVENTION AND EXPOSITION—Municipal Pier, Chicago, Illinois, September 20-24, 1926.

WINTER SECTIONAL MEETING—Washington, D. C., January, 1927.

SOME COMPARISONS BETWEEN ROCKWELL AND BRINELL HARDNESS

By R. C. Brumfield

Abstract

This paper sets forth the results obtained in testing both hard and soft metals by the Rockwell and Brinell hardness tests and establishes the relation between Brinell hardness and each type of Rockwell hardness in which the most influential factor is the area of contact with the piece tested.

A table showing comparative Rockwell and Brinell hardness for various metals is given.

THE Rockwell hardness tester is a recent addition to the class of hardness measuring devices which determine hardness in terms of resistance to permanent indentation. It has been widely adopted because of the rapidity with which tests may be made and because of the small permanent damage done to the piece tested.

The Rockwell hardness test consists essentially in applying a minor initial load to a standard penetrator, adding to this a comparatively large increment called the major load, releasing the original minor load, and reading the amount of movement of the penetrator with respect to the test piece due to the major load. The initial and final readings of penetration are read from an indicating dial while the minor load is on the penetrator. The Rockwell hardness is expressed as a number which is equal to a constant minus the number of gage units of penetration under the major load. This is done in order that high readings may be expressed by large numbers. The dial is so arranged that the number may be read directly. The penetrators used in the present test were a $\frac{1}{16}$-inch steel ball, a $\frac{1}{8}$-inch steel ball, and a 120-degree cone, ground from an amorphous diamond. The minor load in all cases was 10 kilograms. The major load for each of the two balls was 100 kilograms and for the diamond cone 150 kilograms. The constant from which the hardness number is subtracted to give the penetration in gage units is 130 for each

A paper presented before the Hardness Testing Symposium of the Society at the Cleveland Convention, September, 1925. The author, R. C. Brumfield, is assistant professor of civil engineering, Cooper Union, New York City.

of the balls and 100 for the diamond cone. The units in which the resulting penetration are expressed are approximately equal on the average to 0.000075 of an inch for this particular tester, with a maximum local variation of between two and three gage units above and below the average. These later figures are the result of the calibration of the dial and lever of the tester against two 0.0001-inch Ames dials, each of which had previously been calibrated by the Bureau of Standards.

The Brinell hardness used in this comparison is the result obtained by dividing the load in kilograms, used in forcing a standard 10-millimeter ball into the test piece, by the area in square millimeters of the zone of contact of a 10-millimeter sphere with the test piece. This area was found by computation based on the diameter of the impression. The loads used were either 500 or 3000 kilograms, as indicated in Table II.

The test pieces used were about the same as those used in a previous report to this committee before its reorganization, by F. E. Foss and the author, published in the 1922 *Proceedings* of the American Society for Testing Materials, entitled "Some Measurements of the Shape of the Brinell Ball Indentation." Table I of this paper gives the composition of the metals used in the previous report. The designations used for the metals and the order in the tables are the same in this paper as in the previous one. These test pieces were selected because the original Brinell tests had been carefully made and the characteristics of the Brinell indentations were definitely known. The Brinell hardness numbers used in this paper were copied from averages of column 16 of Table II of the 1922 report, with the exception of a few metals at the end of the table, which were added to the original report.

The Rockwell tests were run on these samples following the method recommended by the maker of the instrument as nearly as possible. The oil dashpot provided to prevent too sudden an application of the load was not used, but instead the load was slowly released each time by hand. A number of tests on two specimens furnished by the maker with the hardness numbers etched on them were used as a method of control, to determine at any time whether the penetrator had been damaged to such an extent as to give unreliable readings. It was not found necessary, however, to renew any of the penetrators. The Rockwell hardness numbers listed in Table II are the averages to the near-

est unit of from four to six tests. The first number listed in each case preceded by a "B" was obtained by using the $\frac{1}{16}$-inch ball penetrator with the 100-kilogram load and read from the "B" scale of the dial. The second number listed was obtained by using the $\frac{1}{8}$-inch ball penetrator, and the third number listed

Table I

Compositions of the Metals Used in the Hardness Tests

BRASSES AND BRONZES
All values in per cent

Designation	Copper	Zinc	Lead	Tin	Iron	Phosphorus	Manganese
Hard Brass No. 1 } Soft Brass No. 2 }	62.47	34.88	2.62	0.0	0.03	....	....
Hard Tobin Bronze No. 3 } Soft Tobin Bronze No. 4 }	60.16	39.09	0.04	0.69	0.02	....	....
Hard Phosphor-Bronze No. 5 } Soft Phosphor-Bronze No. 6 }	94.89	0.42	....	4.32	....	0.35	....
Hard Manganese Bronze No. 7 } Soft Manganese Bronze No. 8 }	59.74	38.27	....	0.74	0.90	....	0.85

ALLOY STEELS
All values in per cent

Designation	C	Mn	P	S	Si	Ni	Cr	V
B—1322	0.24	0.85	.....	.....	0.21	29.30	....	....
No. 4—10851	0.11	0.34	0.010	0.031	0.13	3.00	0.58	....
No. 6—9946	0.34	0.59	0.027	0.037	0.20	1.22	0.43	....
No. 4—10966	0.30	0.71	0.010	0.031	0.22	2.84	0.70	....
						2.84	0.71	....
MKD—455	0.45	0.57	0.012	0.019	0.21	....	1.51	0.28
No. 12—4358	0.50	0.68	0.021	0.030	0.23	3.45	....	....

CARBON STEELS
(Per cent of carbon approximate only)

0.5—C—T	0.5-per-cent carbon, tempered
0.5—C—W	0.5-per-cent carbon, water quenched
0.5—C—O	0.5-per-cent carbon, oil quenched
0.5—C—A	0.5-per-cent carbon, cooled in air
0.5—C—N	0.5-per-cent carbon, normal, as it came from the mill
Samples of	0.9-per-cent carbon, steel are indicated by similar notation

OTHER METALS
Exact composition not known

preceded by a "C" was obtained by using the 120-degree cone penetrator with a 150-kilogram load and read from the "C" scale of the dial. In most cases the Rockwell hardness number taken from the bottom of a Brinell impression is also shown to give an idea of the relative hardening effect of the cold work of the Brinell ball on the various metals.

The "B" hardness numbers with the $\frac{1}{16}$-inch penetrator have all been plotted against corresponding Brinell hardness numbers in Fig. 1. Fig. 2 shows Rockwell "B" scale hardness numbers

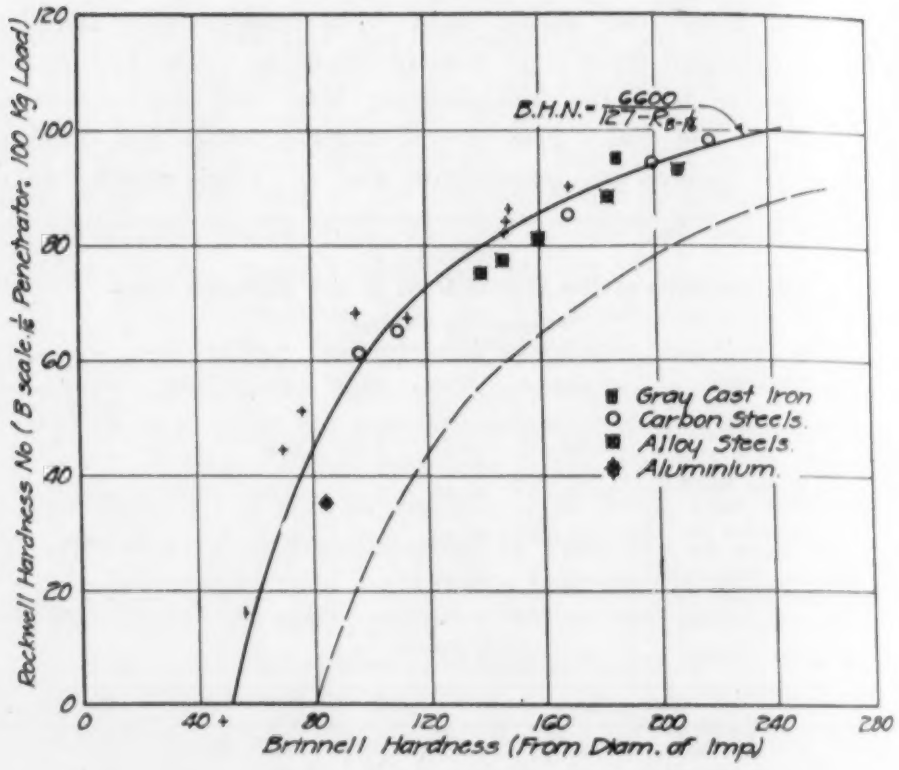

Fig. 1—Rockwell-Brinell Hardness Relation Curve Using a $\frac{1}{16}$-Inch Ball Penetrator.

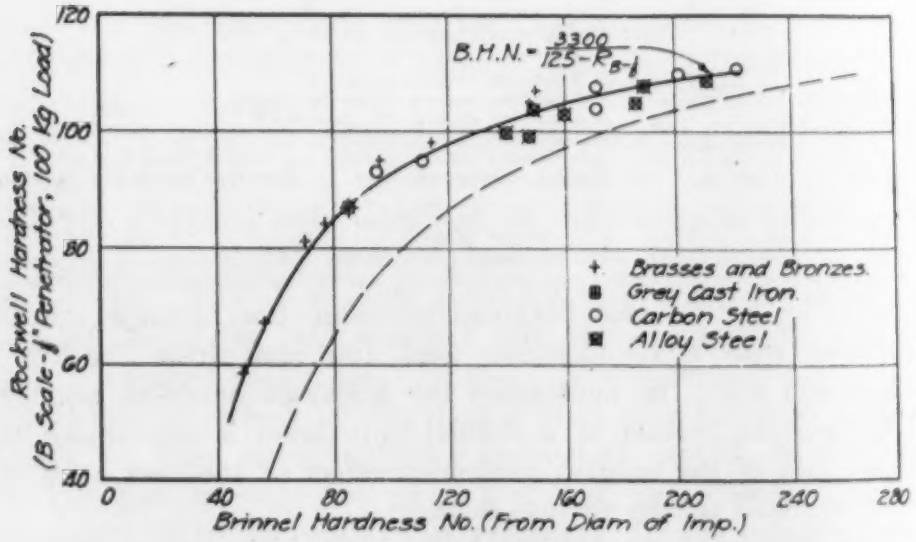

Fig. 2—Rockwell-Brinell Hardness Relation Curve Using a $\frac{1}{8}$-Inch Ball Penetrator.

with the ⅛-inch penetrator against Brinell hardness, and Fig. 3 shows Rockwell "C" scale hardness with the diamond-cone penetrator against Brinell hardness.

It will be noted that some of the Rockwell numbers listed in Table II and plotted on the curves are negative. This is particularly true of the "C" scale numbers. Such numbers are of

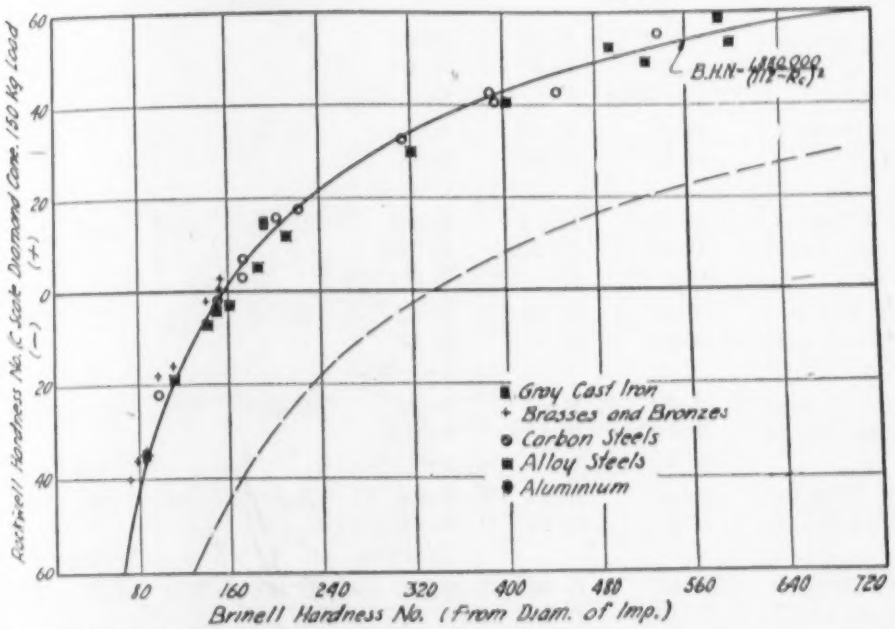

Fig. 3—Rockwell-Brinell Hardness Relation Curve Using a Rockwell Diamond-Cone Penetrator.

course not read directly from the dial, but they represent the number of gage divisions back of the scale zero at which the pointer came to rest when the major load was released, and when subtracted from the scale constant with due regard to sign, they give the depth of penetration in gage units just as the positive numbers do and are, therefore, equally intelligible.

In considering the type of equation which will properly express the relation between Rockwell and Brinell hardnesses, all our experience with the laws of forces would lead us to suspect that the most important factor which finally causes the penetrator to come to rest with respect to the test specimen is the area of contact between the two. If this is true, we should be able to determine the form of these equations by reducing the various Rockwell hardnesses which are now expressed in terms of depth of penetration to terms of kilograms per square millimeter of contact.

Table II
Comparative Rockwell and Brinell Hardness for Various Metals

Designation	Rockwell Hardness Number			Rockwell Hardness in Bottom Brinell Impress.	Brinell Hardness Number		
	Max.	Min.	Average		Max.	Min.	Average
Hard Brass No. 1.	B–68 B–99 C–(–17)	B–67 B–97 C–(–14)	B–67 B–98 C–(–16)	B–89	117	114	115
Soft Brass No. 2.	B–17 B–67	B–15 B–66	B–16 B–67 C–(–63)	B–70	58	57	57*
Hard Tobin Bronze No. 3	B–83 B–105 C–(–1)	B–81 B–105 C–(–2)	B–82 B–105 C–(–2)	B–98	149	149	149
Soft Tobin Bronze No. 4	B–52 B–85	B–50 B–82	B–51 B–84 C–(–36)	B–86	82	75	78*
Hard Phospor Bronze No. 5.	B–87 B–107 C–3	B–85 B–106 C–2	B–86 B–107 C–3	B–99	158	147	151
Soft Phospor Bronze No. 6	B–44 B–82	B–43 B–81	B–44 B–81 C–(–40)	B–81	86	58	71*
Hard Mn. Bronze No. 7	B–86 B–107 C–1	B–84 B–104 C–1	B–84 B–105 C–1	B–99	152	147	150
Soft Mn. Bronze No. 8	B–68 B–96 C–(–17)	B–67 B–95 C–(–19)	B–68 B–95 C–(–18)	B–92	103	91	97*
Carbon Steels ¼ in. thick.							
0.5 Air Cooled	B–90 B–108 C–8	B–89 B–107 C–7	B–90 B–108 C–7	C–30			172
0.5 Oil Cooled	.... C–30	.... C–25	.... C–27	C–37			324
0.5 Tempered	C–34	C–32	C–33	C–38			311
0.5 Normal	B–95 B–111 C–19	B–94 B–109 C–13	B–94 B–110 C–16	C–28			201

Note: The first "B" scale hardness listed in the table refers to the $\frac{1}{16}$-inch ball with the 100-kilogram load. The second refers to the ⅛-inch ball penetrator with the 100-kilogram load. The "C" scale hardness always refers to the diamond cone penetrator with the 150-kilogram load.

*Brinell hardness obtained from the diameter of the impression left by a 10-millimeter ball under a 500-kilogram load. All others were obtained from a 10-millimeter ball and a 3000-kilogram load.

(Table II Continued)

Designation	Rockwell Hardness Number			Rockwell Hardness	Brinell Hardness Number		
	Max.	Min.	Average	in Bottom Brinell Impress.	Max.	Min.	Average
0.5 Water Cooled	C–57	C–55	C–56	C–58			532
0.9 Tempered	C–45	C–42	C–43	C–47			444
0.9 Tempered	C–45	C–41	C–43	C–45			387
0.9 Oil Cooled	C–42	C–40	C–41	C–41			392
0.9 Water Cooled	C–65	C–64	C–65	C–65			774
0.9 Air Cooled	B–99 B–111 C–22	B–96 B–110 C–16	B–98 B–111 C–18	C–33			221
0.9 Normal	B–87 B–104 C–4	B–82 B–103 C–1	B–85 B–104 C–3	C–30			172
0.2 Normal	B–66 B–97 C–(–18)	B–61 B–93 C–(–19)	B–65 B–95 C–(–19)	C–17			112
Alloy Steels							
B–1322	B–78 B–100 C–(–1)	B–76 B–98 C–(–7)	B–77 B–99 C–(–4)	C–30	154	147	149
B–1322 1000°C Water Cooled	B–84 B–105 C–0	B–83 B–103 C–(–5)	B–84 B–104 C–(–2)	C–29	152	148	150
4–10851	B–77 B–101 C–(–7)	B–74 B–99 C–(–8)	B–75 B–100 C–(–7)	C–23	143	138	151
4–10851 1000°C Water Cooled	C–42	C–40	C–41	C–50	404	396	400
12–4358	B–94 B–110 C–13	B–92 B–109 C–11	B–93 B–109 C–12	C–33	213	208	210
12–4358 1000°C Water Cooled	C–53	C–45	C–50	C–57	605	447	521
6–9946	B–85 B–106 C–2	B–78 B–101 C–(–6)	B–81 B–103 C–(–3)	C–17	165	154	161

(Table II Continued)

Designation	Rockwell Hardness Number			Rockwell Hardness	Brinell Hardness Number		
	Max.	Min.	Average	in Bottom Brinell Impress.	Max.	Min.	Average
6-9946 1000°C Water Cooled	C–55	C–49	C–53	C–57	516	463	490
MKD–455	C–31	C–29	C–30	C–45	321	315	318
MKD–455 1000°C Water Cooled	C–60	C–58	C–59	C–63	596	582	586
Gray Cast Iron	B–86 B–109 C–16	B–94 B–105 C–13	B–95 B–108 C–15	C–32			189
Rivet Steel	B–61 B–95 C–(–20)	B–59 B–92 C–(–22)	B–61 B–93 C–(–22)	C–14			98
Rolled Al.	B–36 B–87	B–35 B–87	B–35 B–87 C–(–35)				86*
Very Soft Brass	.... B–59	.... B–56	B–(–3) B–58				49*

For each of the ball penetrators this reduction takes the form:

$$\text{B. H. N.} = \frac{K}{K_1 - R_b} \qquad (1)$$

For the diamond-cone penetrator,

$$\text{B. H. N.} = \frac{K}{(K_1 - R_c)^2} \qquad (2)$$

In each of these equations K and K_1 are constants. They are largely influenced by the load used and the dial scale constant, respectively, which are to be determined from the plotted curves since the factors mentioned are not the sole influences. R is the Rockwell hardness number corresponding to the penetrator used. The constants K and K_1 are determined on the basis of area alone.

	1/16-inch ball	1/8-inch ball	120 degree cone
K	10500	5250	3,330,000
K_1	130	130	100

Curves plotted from these values of the constants are the dashed lines at the right of Figs. 1, 2, and 3.

Determining the constants for Figs. 1, 2, and 3 by simultaneous solution of two average points near the extremes of the range of comparison in each case we have:

For the $\frac{1}{16}$-inch ball penetrator and "B" scale from Fig. 1,

$$\text{B. H. N.} = \frac{6600}{(127 - R_b)} \qquad (3)$$

For the $\frac{1}{8}$-inch ball penetrator and "B" scale from Fig. 2,

$$\text{B. H. N.} = \frac{3300}{(125 - R_b)} \qquad (4)$$

For the 120-degree cone penetrator and the "C" scale from Fig. 3,

$$\text{B. H. N.} = \frac{1{,}880{,}000}{(112 - R_c)^2} \qquad (5)$$

These equations represent average values. They have been plotted on the proper figure in each case as the solid average line. It will be noted that there is a tendency for the brasses and bronzes to fall slightly to the left of this line for each of the penetrators and for the alloy steels to fall to the right. It is possible then that with an increased number of points a more accurate equation might be written for any given material by slightly altering the constants of the appropriate equation. The number of points here available is not sufficient to warrant any such refinement. The forms of the equations appear to be substantially correct and the equations themselves should be useful until considerably more data are available.

We may take equations (3), (4), and (5) and equate them to each other, thus obtaining a relation between the three types of Rockwell hardness:

$$R_{b-\frac{1}{8}} = \frac{R_{b-\frac{1}{16}} + 62}{2} \qquad (6)$$

$$R_c = 112 - 16.9\sqrt{127 - R_{b-\frac{1}{16}}} \qquad (7)$$

Equations (6) and (7) give two of these relations which inter-relate hardness numbers obtained with the various types of Rockwell penetrators.

The dashed line to the right in each of the Figs. 1, 2, and 3,

shows the true position of the Rockwell relation curve if Rockwell hardness is interpreted in terms of the Brinell hardness definition, i. e., in terms of kilograms per square millimeter of contact with the test specimen. The fact that the actual curves in all cases fall to the left of these hypothetical curves means that for all the types of Rockwell penetrator shown the actual average unit fiber stress at which they reach equilibrium in the test piece is greater than the unit fiber stress at which the 10-millimeter Brinell ball reaches equilibrium in the same test piece.

It should be noted in connection with these curves that closer numerical agreement between successive tests by the Rockwell method on the same piece of hard material does not necessarily mean more consistent results than if the hardness had been measured by the Brinell ball. In the region of Rockwell hardness C-50, a variation of one unit Rockwell hardness corresponds to a variation of about fourteen units Brinell hardness. The two systems do not vary the same numerically until they reach the softer metals in the region of Rockwell hardness C-(-60).

Figs. 4, 5, and 6 have been included to show a comparison with the previous report to the committee on the shape of the indentation made by the Brinell ball. Fig. 4 shows a cross section of the impression of the $\frac{1}{16}$-inch ball in alloy steel No. 12-4358. The reading for this particular impression was B-94. This is only six units of hardness below 100, beyond which the ball penetrator is not recommended for use. It will be noted that the plotted points which were measured from the impression coincide closely with the dotted line which represents the true shape of a $\frac{1}{16}$-inch sphere. From this it may be concluded that within the limits set for use of the $\frac{1}{16}$-inch ball penetrator the impression left is practically the shape of the ball. Since this is true, depth measurement is just as reliable for computing area of contact with the test piece as is diameter measurement. As previously pointed out, computations of average bearing stresses based on the depth of penetration by the Rockwell penetrators give considerably higher fiber stresses than are obtained for the Brinell ball for the same test piece. This fact must then be due to the relative sizes of the Rockwell and Brinell penetrators with a possibility of the relative loads having some influence.

Fig. 5 shows a cross section of the impression left by the diamond cone penetrator in soft brass No. 2. This was the softest

specimen tested with the diamond cone penetrator. The cross section is included largely to indicate the true shape of the penetrator on the assumption that the cone would not distort appreciably in the soft brass. The dashed line indicates a 120-degree angle, and it will be noted that the actual measurements of the

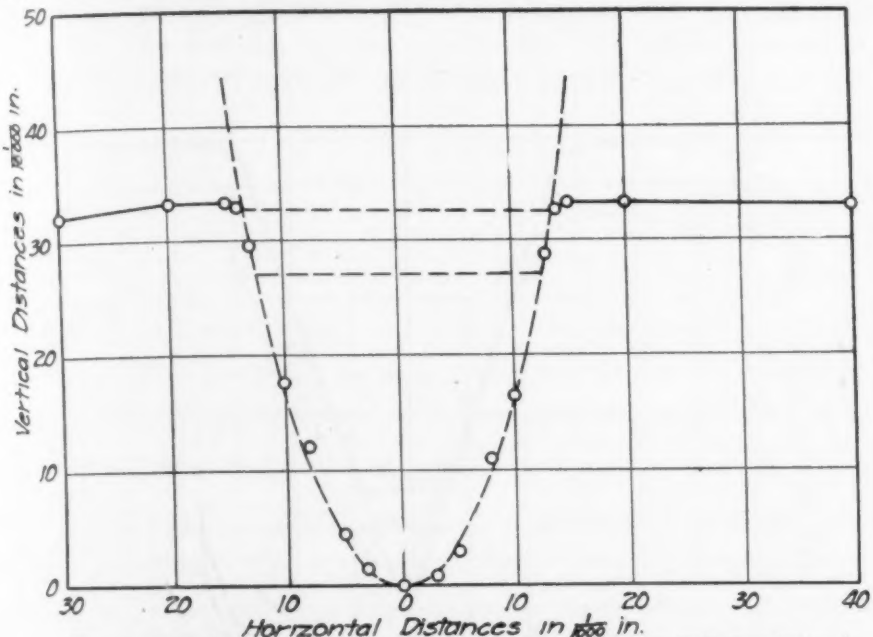

Fig. 4—Cross-Section of Impression by a 1/16-Inch Rockwell Ball Penetrator in Alloy Steel No. 12-4358. The Hardness for this Impression was Rockwell B-94.

impression coincide closely with this. The impression shown in Fig. 5 and the one shown in Fig. 6 both indicate the rounded point on the cone with a diameter between two and three thousandths of an inch. The makers grind a definite zone of a sphere at the point of the cone but the diameter of this rounded point is not necessarily as great as is indicated, for the reason that this dimension might also have been affected by the diameter of the needle point used for taking the measurements. The average indicated hardness for the metal, of which Fig. 5 is a cross section of the impression, is C-(-63). While this is not necessarily the indicated hardness for this particular impression it could not be far from it. If C-(-63) be assumed to be the hardness number for the impression shown, we have from the figure the indicated penetration under the 10-kilogram load was 0.0023 inch and under the total load of 160 kilograms was 0.0151 inch. These penetrations are not in proportion to the loads, the first being greater than the second.

Fig. 6 shows the impression left by the diamond cone in the 0.90 per cent carbon steel which was water-quenched from 1832 degrees Fahr. (1000 degrees Cent.). This was indicated by the Rockwell tester to be the hardest piece tested. The cross section is included to indicate the distortion of the cone in very hard materials. It will be noted that the normally 120-degree cone left

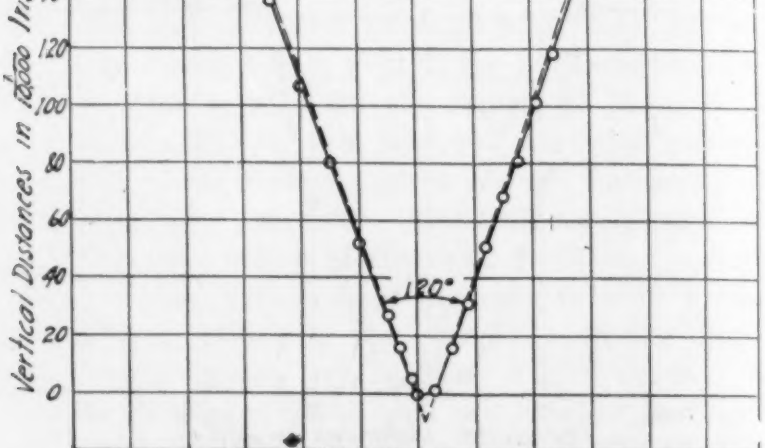

Fig. 5—Cross-Section of Impression by a Rockwell Diamond-Cone Penetrator in Soft Brass No. 2.

a permanent impression of about 127 degrees. The flattening would have been greater during loading by an amount depending on the elasticity of the steel. If the cone had retained its 120-degree angle the indicated Rockwell hardness would have been about 5 units lower, assuming the same diameter of impression.

The indicated hardness for the impression shown in Fig. 6 was C-65. This hardness number indicated a penetration of the metal by the cone under the 10-kilogram load of 0.00006 inch and under the 160-kilogram load of 0.00263 inch. No great degree of accuracy is claimed for the first figure listed, but, if it be assumed even approximately correct, the proportionality of the penetrations under the two loads is reversed from that indicated in Fig. 5. This would be accounted for by the fact that in the case of the hard metal the blunted point was only partially imbedded under the 10-kilogram load.

Fig. 6 also gives some indication as to the durability of the diamond cone, as this impression was one of the last ones made. The cone had previously been used to make about two hundred and fifty impressions. It was new when received.

The Rockwell "C" scale hardness in the bottom of the Brinell impression which is shown in Table II has been plotted in Fig. 7 against the average normal Rockwell "C" scale hardness for the same metal. The "B" scale hardness in the bottom of

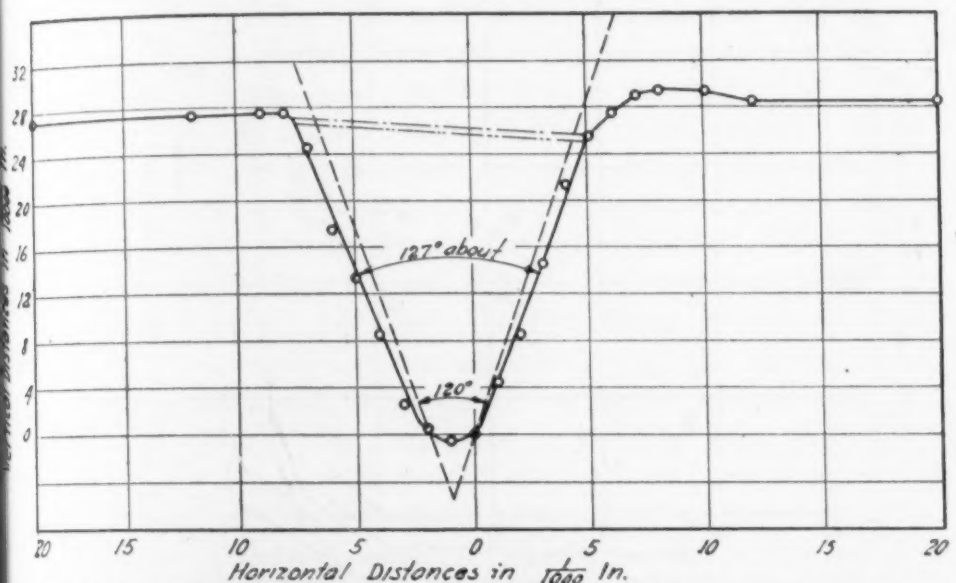

Fig. 6—Cross-Section of Impression by a Rockwell Diamond-Cone Penetrator in 0.90 Per Cent Carbon Steel, Water-Quenched. The Hardness for this Impression was Rockwell C-65.

the Brinell impression taken for the brasses and bronzes has been reduced to its "C" scale equivalents by means of formula (7). To prove that the increased hardness in the bottom of the Brinell impression was not due to the spherical shape of the surface, the metal surrounding one of the Brinell impressions in soft Tobin bronze No. 4 was ground completely down to the plane of the bottom of the impression. Slightly staggered Rockwell readings were then taken at distances progressively increasing by $\frac{1}{16}$ of an inch out from the center of the original impression. These showed a gradual falling off from the original indicated hardness in the bottom of the impression read as B-86 to the indicated hardness of the undisturbed metal of about B-50. From this it was concluded that the spherical shape of the surface in the bottom of the impression had little effect on the Rockwell reading.

It will be noted from the curve that the Rockwell test indi-

cates that the Brinell ball hardens the metal directly under it for most metals. This hardening effect is relatively greater for the softer metals and ceases to exist when the region of hardness about Rockwell C-60 is reached. This would indicate that a hardness of C-60 is about as great as is capable of being obtained by the type of cold work which the Brinell ball does. Our knowledge

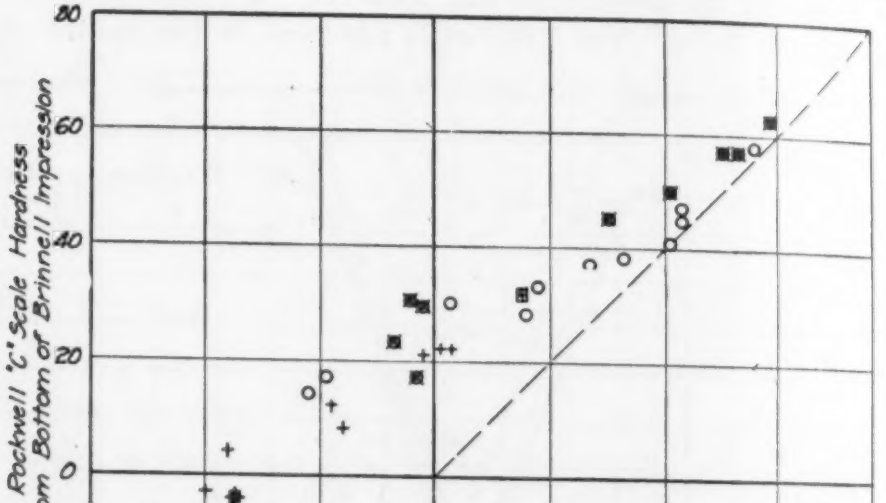

Fig. 7—Showing Relative Hardening Effect of the Brinell Ball Due to Cold Work, as Shown by the Rockwell Hardness Tester.

of the effect of cold work would lead us to suspect some such condition as shown in Fig. 7 without the evidence of the tests. We must recognize, however, that the hardening effect of the Brinell ball is probably shown relatively and not actually by Fig. 7 because the Rockwell test by its nature must also cause an effect similar in nature, but different in degree to that caused by the Brinell ball.

Such a hardening effect of the ball on the metal as that indicated means that the Brinell ball in metals which it is capable of hardening by the type of cold work which it does is underlain by a cushion of hardened metal similar to the pressure bulb on the end of a foundation pile. The tendency of this cushion is to increase the effective bearing area of the ball on the undisturbed metal as compared with the actual area of contact. Since this cushioning effect decreases as the primitive hardness of the metal

increases, the Brinell test tends to decrease the range in actual primitive hardness between soft and hard metals.

Such an explanation of the action of the Brinell ball as above outlined offers a possible reason for the well known fact that, using a 10- millimeter ball, the indicated Brinell hardness of many metals increases with the load applied up to some load which gives a maximum hardness after which the indicated hardness again drops slightly, for further increase in load. The indicated hardness would increase with the load due to the growth of the pressure cushion under the ball until sufficient load was attained to crack the brittle cushion, after which the ball would sink farther into the softer surrounding metal, just as a wagon wheel sinks through a crust of frozen ground. Such an explanation of the action of the Brinell ball would allow a straight line variation between load and penetration for the harder metals, but would make it increasingly unlikely for the softer metals. The two increments in penetration for the $\frac{1}{16}$-inch ball shown in Fig. 4 are not in proportion to the loads, the first being greater than the second. If this is the correct explanation of the action of the Brinell ball, the Brinell hardness of the harder metals which are incapable of being further hardened by the cold work of the Brinell ball should be independent of the load, and the straight line variation between load and depth of penetration should be maintained, except for the distortion of the ball. The author has considerable evidence that the variation between the load and depth of penetration for some of the softer metals is not a straight line in the early stages of the loading, but that the rate of penetration decreases slightly up to some load which would give the maximum indicated hardness after which the penetration usually proceeds practically as a straight line ratio. The above statement is true for both the Brinell ball and the Rockwell ball. The minimum rate of penetration with the Rockwell ball occurred between forty and sixty kilograms of load and so could not ordinarily be detected, since 60 kilograms is the minimum load capable of being applied with the standard machine. Gray cast iron was the most pronounced example of this action, the variation in the rate of penetration being enough to affect the Brinell hardness as much as thirty per cent.

If the minute cracks suggested above exist in the metal at any time, their presence might possibly be detected with the mi-

croscope. No time has been available for such an examination in connection with this paper and the foregoing has accordingly been suggested as only a tentative explanation of facts which have been well recognized in the past.

Conclusions

1. There is a relation between Brinell hardness and each of the types of Rockwell hardness in which the most influential factor is the area of contact with the test piece.

2. Rockwell penetrators of all types used come to rest in the test piece at higher average fiber stresses than does the 10-millimeter Brinell ball.

3. The Rockwell test tends to differentiate more widely between two fairly soft metals than it does between two fairly hard metals when both pairs differ by the same amount of Brinell hardness.

4. A greater numerical consistency of the Rockwell test for the hard metals is, therefore, likely to be apparent and not real.

5. The limit of hardness, B-100, beyond which the ball penetrator is not recommended for use, is sufficiently low so that the impression left by the ball is substantially the shape of a $\frac{1}{16}$-inch sphere.

6. The diamond cone is accurately ground and the particular one used had a point which was rounded to possibly less, but not more, than 0.0025 inch diameter.

7. The diamond cone flattens appreciably in the hard metals, thus indicating higher hardness than if it retained its shape.

8. The action of the Brinell ball is to harden the metal directly under it. This is indicated by the Rockwell test.

9. The maximum hardness obtainable due to the cold work of the Brinell ball is about Rockwell C-60.

10. The hardening effect due to the cold work of the Brinell ball is not as great as C-60 in all metals, but in general the percentage of increase in hardness due to this cold work increases as the indicated Rockwell hardness decreases.

11. The pressure cushion of hardened metal so formed underneath both the Brinell ball and the Rockwell ball probably affects the rates of penetration of the balls at various loads, thus affecting the indicated hardness.

SOME CHARACTERISTICS OF QUENCHING CURVES

By H. J. French and O. Z. Klopsch

Prefatory Abstract

In this report is given a discussion of time-temperature cooling curves at the center of steel samples of various sizes and shapes quenched into ordinary coolants such as water, a commercial quenching oil and air. Based on the described experiments a method is outlined by which cooling curves for various sizes and shapes quenched from various temperatures can be derived, provided the curve for one size from one quenching temperature is available and one constant is known for the coolant. Typical examples are given.

I. Introduction

In a recent report on mass effects in quenching[1] certain definite relations were developed by the authors between the size and shape of steel quenched and the center cooling velocity taken at 720 degrees Cent. For rounds, spheres and plates, this cooling velocity was proportional to the surface per unit of volume raised to some power greater than 1 and less than 2. If V represents the center cooling velocity, taken at 720 degrees Cent., S is the surface area, W is the volume, n and C_2 are constants depending upon the coolant, etc., these relations may be represented by the equation

$$V = \left(\frac{S}{W}\right)^n C_2 \qquad (1)$$

It was also demonstrated that the cooling time for certain intervals for small samples was inversely proportional to the designated cooling velocity. Thus, if T is the cooling time for

[1]Bureau of Standards Technologic Paper No. 295.

Published by permission of the Director of the National Bureau of Standards, Department of Commerce, Washington, D. C. This report will also be published as a Technologic Paper by the Bureau of Standards.

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a given temperature change, C and C_1 are constants, the relations referred to may be represented by the equation

$$T = \frac{CC_1}{V} \qquad (2)$$

It may naturally be inferred from equations (1) and (2) that some very general relations exist between cooling times at the center of various sizes of the simple shapes (rounds, spheres and plates), but in the report already referred to attention was largely directed to the cooling velocity taken at 720 degrees Cent., as this had previously been shown[2] to be the best single factor from time-temperature cooling curves to represent the hardening produced in small or moderate size sections of carbon steels. While such cooling velocity relations are of general interest, from several viewpoints, frequently questions arise regarding the cooling at lower temperatures and comparisons are desired of the greater part of the cooling range from the quenching to the final temperatures.

For example, the center temperatures may be desired in the forging of large masses, or the exact time required at which steel samples may be removed to avoid cracking without danger of reducing the center hardness, or otherwise modifying those properties which are dependent upon the manner of cooling through the hardening transformations.

Such cooling curves are also useful in comparisons of various coolants and particularly in determining what sizes of the simple shapes may be fully hardened to the center when made from steels for which the critical cooling velocities are known. Again they will show, at least in a general way, the range in sizes of the simple shapes which may be quenched to advantage in special coolants.

Aside from this, however, center cooling curves form the basis of comparison for a study of cooling at the surface and other portions of steel samples of various sizes and shapes, a subject which it is hoped may be considered at a later date.

It is the purpose of this report to summarize experiments already reported, together with results of additional tests, in such a way that it will be possible to construct by simple calculations

[2]H. J. French and O. Z. Klopsch. Quenching Diagrams for Carbon Steels in Relation to Some Quenching Media for Heat Treatment. TRANSACTIONS, American Society for Steel Treating, Vol. 6, Sept., 1924, p. 251.

practically the entire time-temperature cooling curves (from the quenching temperature to about 200-250 degrees Cent.) for the center of various sizes of the simple shapes when quenched from any temperature at or above 720 degrees Cent. into typical coolants such as water, an oil and air. In the discussion of data the similarities and salient features of the quenching curves will, of course, be developed and will facilitate making similar compilations for other of the many coolants now used industrially or for experimental work.

II. Materials and Test Methods Used

As in previous cases, carbon or carbon-chromium steel samples of different sizes and shapes were quenched from various temperatures into motionless water, a commercial quenching oil (called No. 2 oil) or air, each at 18 to 23 degrees Cent. A description of equipment and methods of procedure employed has already been given.[3]

It should be pointed out that in both the previous report and the tests now to be discussed, thermal effects of transformations were disregarded. Smooth curves were drawn from points above the transformations to points below and, therefore, cooling at intermediate temperatures in the neighborhood of 500 to 650 degrees Cent. was approximated. Despite objections which may be raised to such procedure, it seems preferable to the use of a transformation-free metal. The thermal properties of all such metals as have been used or suggested for this purpose are quite different from those of ordinary steels, at least in some portions of the cooling range, and will not yield results closely approaching those obtained with the ordinary steels to which such treatments as are here considered are ordinarily applied and of most importance.

Experimental Results

1. Cooling from a Fixed Temperature

If in equation (2) there is substituted the value of V given by equation (1) the following is obtained.

$$T = \frac{CC_1}{C_2}\left(\frac{W}{S}\right)^n \qquad (3)$$

Since C, C_1 and C_2 are constants, the product of C and C_1 divided

[3]Refer to footnotes (1) and (2).

by C_2 will also be a constant. Equation (3) may then be re-written as follows:

$$T = C_3\left(\frac{W}{S}\right)^n \qquad (4)$$

This shows that the cooling time for a given temperature change at the center of small sizes of the simple shapes is proportional to the reciprocal of the surface per unit of volume raised to some power "n." The numerical values of this exponent have already been determined for a number of coolants and found to vary between 1 and 2; methods for determining the value of "n" for other coolants have also been outlined. To apply equation (4) it is then only necessary to evaluate the constant C_3 and determine upon what variables in quenching it is dependent in addition to the cooling range considered. With the evaluation of the constant C_3 it should be possible to construct the complete time-temperature cooling curve for various sizes and shapes.

2. Relation of Cooling Times to Steels and Shapes Quenched

In the experimental work to be described all small samples were made of either high carbon or high carbon chromium steels, whereas the largest sections were prepared from commercial low carbon steels. These variations in the composition of the steel are undesirable, especially from the standpoint of the cooling at the lowest temperatures, for, as shown at the right side of Fig. 1, they introduce variations in the cooling times. With low carbon the cooling is more rapid in the range below about 500 degrees Cent. but at higher temperatures such changes in composition produce changes in the cooling which are small and not easy to measure by the methods used in this investigation. It should, therefore, be kept in mind that the numerical values for certain constants later developed will give at the lower portions of the cooling range times slightly large for small sections of low carbon steel and times which are somewhat low for large sections of high carbon steels. As most previous work along similar lines with large sections has been with low carbon steels the authors would have repeated with such steels many of the experiments already made with small sections of high carbon steel, were it not for the fact that the general relations and principles to be outlined are considered of greater importance than specific numerical values.

The authors have already shown that the cooling velocity in

the neighborhood of 720 degrees Cent. is a function of the surface per unit of volume and does not vary with the shape of sample. Likewise, it has been shown that the cooling time for certain intervals is inversely proportional to this cooling velocity. At the left side of Fig. 1 it is shown that within limits of experimental error that the entire cooling as well is independent of the shape

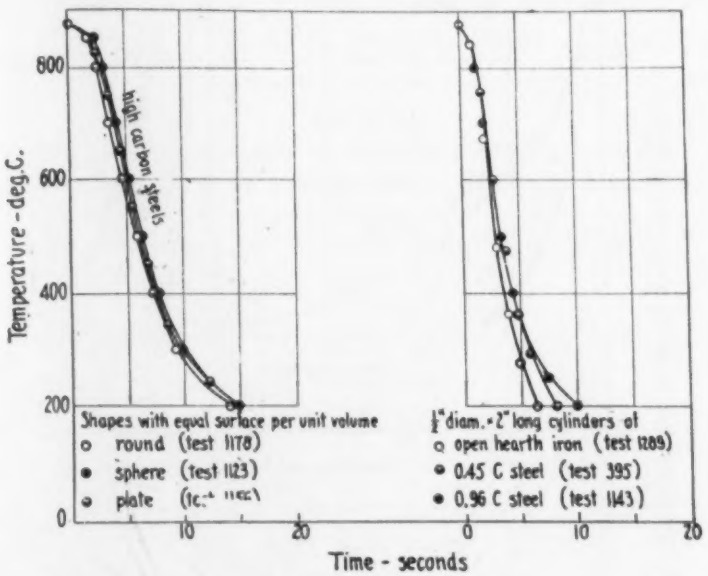

Fig. 1—Effect of Composition of Steel and Shape of Sample on Time-Temperature Cooling Curves Taken at the Center of Small Masses.

of sample. While this has been checked only on small and moderate-size sections, it is a reasonable assumption that the law as stated should be more nearly correct the larger the specimens. Further indirect evidence for the validity of this assumption will be found in data given in subsequent sections of this report.

3. *Data Showing That in a Given Coolant the Center of a Given Steel Sample Cools in Equal Times to Equal Proportions of the Cooling Range*

Before taking up in detail the general relations between cooling times and the size and shape of steel, the effect of variation in quenching temperature on the manner of cooling will be considered. The times required to cool the center of spheres of different sizes from 730 (or 760), 815, 875, and 950 degrees Cent. to various lower temperatures in water, a commercial quenching oil and air are summarized in Tables I and II. If these times

are plotted against temperature expressed as a proportion of the cooling range (quenching temperature to coolant temperature), curves similar to those in Fig. 2 are obtained.[3a] It will be observed that the center of the sample cools to equal proportions

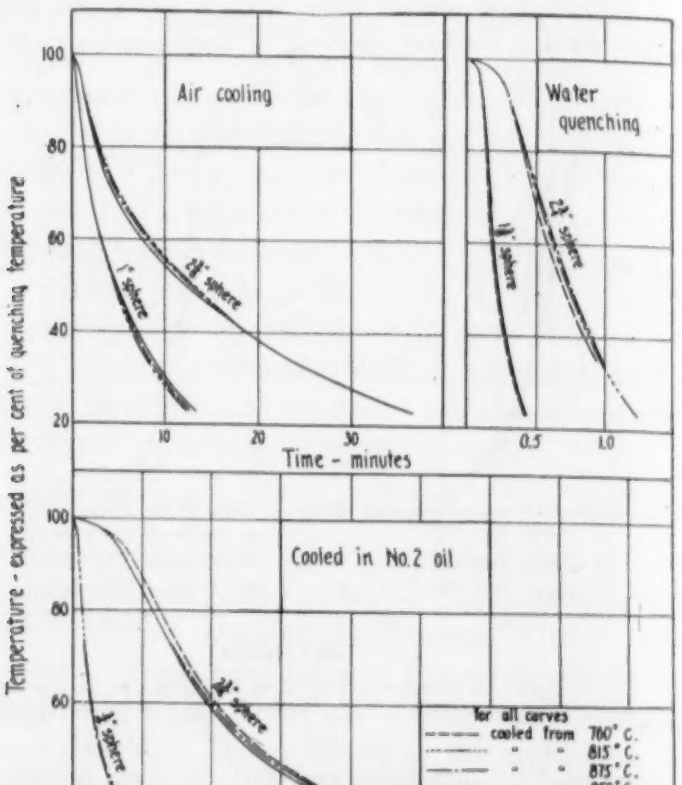

Fig. 2—Effect of Quenching Temperature on the Center Cooling Curves of Steel Samples Immersed in Various Coolants.

Note that all Temperatures are Expressed as a Proportion of the Initial (Quenching) Temperature. (Refer to Footnote 3a of the Text.)

of the cooling range in equal times. It therefore follows that any relations developed for one initial temperature are immediately applicable to any other, provided only that temperature is

[3a] For coolants at atmospheric temperatures, no appreciable error is introduced and calculations are simplified if temperatures are expressed as a proportion of the temperature of quench instead of as a proportion of the cooling range. This method was used in plotting Figs. 2 and 6 and in deriving data in Tables I and III, relating to coolants at ordinary temperatures. It will introduce greater errors for coolants at much higher temperatures.

expressed as a proportion of the cooling range. However, this has only been shown to apply to quenching from above the transformations, at or above about 720 degrees Cent.

4. Evaluation of the "Time-Constant"

In Table II are tabulated the times required for cooling from 875 degrees Cent. to various lower temperatures. These numerical values were secured from a large number of cooling

Table I

Effect of Quenching Temperature on the Center Cooling of Steel Specimens of Various Sizes and Shapes in Different Media

Size, Inches	Run No.	Coolant	Quench Temp. ° C.	Time in Minutes to Cool to Proportion of Quenching Temperature Indicated[1] 97.2 %	91.4 %	80.0 %	68.6 %	57.2 %	45.7 %	34.3 %	22.9 %
2¾ Sph.	1322	Water	760	0.21	0.30	0.39	0.49	0.61	0.76	0.93	.....
½x2 Rd.	1324	Water	760	0.018	0.026	0.035	0.044	0.055	0.068	0.093	.....
½x2 Rd.	1325	Water	760	0.017	0.024	0.033	0.043	0.052	0.063	0.082	.....
2¾ Sph.	1333	No. 2 Oil	760	0.28	0.43	0.63	0.84	1.13	1.62	....	.....
½x2 Rd.	1331	No. 2 Oil	730	0.025	0.038	0.064	0.095	0.145	0.255	0.487	.....
1 Sph.	1495	Air	760	0.18	0.53	1.30	2.25	3.31	5.60	8.30	13.0
1⅞ Sph.	1496	Air	760	0.25	0.75	1.85	3.33	5.42	6.47	12.22	18.50
1 Sph.	1509	Water	815	0.029	0.048	0.068	0.089	0.111	0.139	0.188	0.270
1⅞ Sph.	1510	Water	815	0.088	0.139	0.192	0.256	0.323	0.402	0.520	0.780
2¾ Sph.	1511	Water	815	0.203	0.292	0.413	0.542	0.673	0.817	0.992	1.25
¾ Sph.	1489	No. 2 Oil	815	0.033	0.050	0.077	0.111	0.163	0.258	0.427	0.883
1⅜ Sph.	1491	No. 2 Oil	815	0.087	0.125	0.192	0.278	0.422	0.622	1.07	.....
1⅞ Sph.	1492	No. 2 Oil	815	0.15	0.205	0.300	0.437	0.637	0.933	1.52	.....
2⅜ Sph.	1493	No. 2 Oil	815	0.20	0.28	0.46	0.66	0.903	1.27	2.12	.....
¾ Sph.	1488	Air	815	0.133	0.327	0.783	1.53	2.6	4.0	5.93	9.5
1 Sph.	1487	Air	815	0.183	0.408	1.07	2.10	3.58	5.43	8.08	12.42
1⅜ Sph.	1486	Air	815	0.30	0.667	1.63	3.15	5.38	8.33	12.2	18.33
1⅞ Sph.	1485	Air	815	0.39	0.92	2.33	4.55	7.80	12.25	18.2	28.00
2⅜ Sph.	1484	Air	815	0.52	1.17	2.97	5.67	9.75	15.50	26.67	36.67
2¾ Sph.	1483	Air	815	0.72	1.52	3.71	7.32	12.67	20.37	30.00	48.00
1⅜ Sph.	1513	Water	950	0.080	0.110	0.150	0.183	0.219	0.263	0.325	0.423
2⅜ Sph.	1514	Water	950	0.146	0.223	0.313	0.403	0.500	0.620	0.771	1.029
2⅜ Sph.	1507	No. 2 Oil	950	0.187	0.300	0.445	0.607	0.817	1.17	1.83	3.37
2¾ Sph.	1508	No. 2 Oil	950	0.233	0.383	0.670	0.767	1.03	1.45	2.33	4.00
¾ Sph.	1497	Air	950	0.117	0.270	0.667	1.22	2.17	3.57	5.40	8.50
1 Sph.	1498	Air	950	0.183	0.453	1.11	2.03	3.63	5.95	8.92	13.63
1⅜ Sph.	1499	Air	950	0.267	0.667	1.58	2.97	5.27	8.75	13.58	21.00
2⅜ Sph.	1501	Air	950	0.482	1.000	2.50	4.78	6.65	14.87	23.33	36.50
2¾ Sph.	1502	Air	950	0.617	1.28	3.03	5.88	10.67	18.37	29.00	45.17

[1]For example, the range from 1000-600 degrees Cent., when quenching from 1000 degrees Cent., is given as 60 per cent. (Refer to footnote 3a of the text.)

curves taken when quenching the specified sizes and shapes into water, No. 2 oil and air. Included also are values taken from curves for large sections published by Law[4] and Bash[5]; Harper's data have not yet been published.[6] From these data, the values

[4]E. F. Law: Effect of Mass on Heat Treatment. JOURNAL, *Iron and Steel Institute*, 97, 333 (1918).

[5]F. E. Bash: Forging Temperature and Rate of Heating and Cooling of Large Ingots. *Transactions*, American Institute of Mining and Metallurgical Engineers, "Pyrometry Volume," p. 614 (1920).

[6]The cooling curves at the center of the 12-inch cube quenched in water and also cooled in air were taken from experiments recently carried out by J. F. Harper, Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin.

Table II

Effect of Size and Shape on the Center Cooling when Steels are Cooled in Various Media

Size, Inches	Run No.	Cooled in	S W	Time in Minutes to Cool from 875 Degrees Cent. to 850	800	700	600	500	400	300	250	200	"X" Minutes
	Spheres												
¾	1229	Water	8	0.021	0.028	0.039	0.05	0.063	0.081	0.108	.....	.....	0.018
1⅜	1124	Water	4.46	0.07	0.092	0.124	0.155	0.19	0.233	0.292	0.337	0.415	0.065
1⅝	1125	Water	3.7	0.087	0.118	0.165	0.208	0.258	0.318	0.403	0.466	.....	0.079
1⅞	1126	Water	3.2	0.103	0.147	0.207	0.264	0.33	0.409	0.522	0.600	0.74	0.090
2⅜	1127	Water	2.58	0.163	0.223	0.312	0.406	0.512	0.631	0.788	0.903	.....	0.147
2¾	1128	Water	2.1	0.233	0.305	0.426	0.558	0.71	0.87	1.07	.....	.....	0.22
4¾	1544	Water	1.26	0.60	0.87	1.23	1.57	1.85	2.15	2.5	2.70	2.97	0.55
	Rounds												
½x2	1143	Water	9	0.015	0.022	0.033	0.045	0.058	0.075	0.100	.....	.....	0.013
1¼x5	1176	Water	3.6	0.095	0.14	0.192	0.242	0.293	0.348	0.413	0.460	.....	0.083
1½x4½	393	Water	3.11	0.117	0.170	0.243	0.300	0.357	0.425	0.510	0.563	0.640	0.093
1½x6	1170	Water	3.00	0.12	0.157	0.217	0.273	0.337	0.400	0.483	0.54	0.627	0.108
2x6	394	Water	2.34	0.19	0.27	0.39	0.48	0.58	0.68	0.82	0.90	0.98	0.167
	Plates												
⅜x⅜x1½	1081	Water	8	0.014	0.023	0.040	0.056	0.071	0.087	0.106	0.115	0.127	0.0125
⅝x⅜x1½	1088	Water	8	0.018	0.029	0.046	0.063	0.078	0.095	0.114	0.127	0.142	0.016
⅜x⅜x1½	1102	Water	8	0.015	0.025	0.042	0.057	0.071	0.087	0.106	0.117	0.129	0.0125
½x2x2	1082	Water	6	0.024	0.039	0.063	0.084	0.107	0.132	0.163	0.180	0.200	0.021
½x2x2	1103	Water	6	0.025	0.038	0.062	0.085	0.110	0.137	0.168	0.187	0.205	0.0233
½x2x2	1152	Water	6	0.028	0.048	0.075	0.099	0.125	0.155	0.193	0.222	.....	0.025
⅞x2¼x2¼	1083	Water	5.33	0.027	0.047	0.080	0.112	0.140	0.170	0.202	0.220	0.243	0.0233
⅞x2¼x2¼	1154	Water	5.33	0.040	0.061	0.084	0.108	0.133	0.163	0.210	0.243	.....	0.031
1x2¾x2¾	1104	Water	4.36	0.038	0.065	0.105	0.142	0.175	0.213	0.267	0.280	0.305	0.034
1x2¾x2¾	1133	Water	4.36	0.040	0.067	0.107	0.142	0.174	0.205	0.238	.....	.....	0.035
.945x4x4	1100	Water	3.12	0.100	0.152	0.213	0.262	0.313	0.365	0.418	.....	.....	0.088
	Spheres												
¾	1217	No. 2 Oil	8	0.032	0.050	0.078	0.107	0.150	0.233	0.388	0.516	.....	0.028
1	1215	No. 2 Oil	6	0.050	0.079	0.117	0.160	0.225	0.372	0.675	0.908	.....	0.043
1	1265	No. 2 Oil	6	0.050	0.075	0.110	0.148	0.220	0.337	0.646	.....	.....	0.043
1⅜	1221	No. 2 Oil	4.46	0.087	0.135	0.213	0.303	0.428	0.606	0.927	.....	.....	0.08
1⅜	1222	No. 2 Oil	4.46	0.088	0.128	0.193	0.268	0.379	0.583	1.00	.....	.....	0.08
1⅞	1201	No. 2 Oil	3.2	0.13	0.23	0.38	0.57	0.85	1.27	.....	.....	.....	0.108
1⅞	1207	No. 2 Oil	3.2	0.14	0.21	0.31	0.43	0.60	0.98	.....	.....	.....	0.133
1⅞	1211	No. 2 Oil	3.2	0.15	0.22	0.33	0.45	0.63	1.08	1.65	2.12	.....	0.135
2¾	1212	No. 2 Oil	2.1	0.25	0.37	0.54	0.78	1.08	1.57	2.28	.....	.....	0.217
4¾	1543	No. 2 Oil	1.26	0.73	1.10	1.60	2.10	2.70	3.7	5.8	7.5	9.85	0.67
11¾	1536	No. 2 Oil	0.533	3.55	5.12	7.10	8.75	.....	.....	.....	.....	.....	3.2

	Rounds												
¾x3	1240	No. 2 Oil	6	0.05	0.083	.....	.....	.....	.....	.....	.....	.....	0.043
⅝x3	1263	No. 2 Oil	6	0.038	0.068	0.12	0.15	0.263	0.403	0.657	.....	.....	0.037
1x4	1257	No. 2 Oil	4.5	0.053	0.088	0.160	0.237	0.323	0.470	0.82	.....	.....	0.047
1¼x5	1244	No. 2 Oil	3.6	0.113	0.172	0.26	0.35	0.48	0.73	.....	.....	.....	0.102
	Spheres												
2⅜	1468	Air	2.58	0.60	1.25	2.83	5.33	9.5	15.5	23.5	29.0	36.8	0.55
4¾	1541	Air	1.26	1.50	2.83	5.83	11.0	20.0	31.0	46.83	60.0	76.67	1.25
11¼	1535	Air	0.533	6.3	12.0	25.5	40.0	58.0	82.0	120.5	145.0	185.0	5.5
	Rounds												
½x2	388	Air	9	0.10	0.30	.....	.....	.....	.....	.....	.....	.....	0.067
½x2	1239	Air	9	0.083	0.242	0.633	.....	.....	.....	.....	.....	.....	0.05
½x2	1476	Air	9	0.12	0.28	0.67	1.28	2.25	3.63	5.38	6.70	8.56	0.100
½x2	1540	Air	9	0.11	0.35	0.91	1.57	2.33	3.47	5.2	6.46	8.17	0.083
¾x3	1241	Air	6	0.167	0.44	1.11	.....	.....	.....	.....	.....	.....	0.133
⅝x3	1248	Air	6	0.15	0.41	1.08	.....	.....	.....	.....	.....	.....	0.10
1x4	1243	Air	4.5	0.21	0.55	1.45	.....	.....	.....	.....	.....	.....	0.15
1¼x5	1245	Air	3.6	0.30	0.73	1.9	.....	.....	.....	.....	.....	.....	0.233
1½x6	1247	Air	3.0	0.43	0.98	2.47	.....	.....	.....	.....	.....	.....	0.35
2x8	1250	Air	2.25	0.70	1.40	3.25	.....	.....	.....	.....	.....	.....	0.60

				Time in Minutes to Cool from 882 Degrees Cent. to									
	Cubes			857	806	705	605	504	403	302	252	202	
12	Harper[1]	Water	0.500	7.5	10.3	13.1	14.4	15.6	17.1	19.1	20.3	21.6	7.0
12	Harper[1]	Air	0.500	9.5	17.0	34.2	54.0	78.0	110.0	154.0	184.0	232.0	9.0

				Time in Minutes to Cool from 900 Degrees Cent. to									
	Cubes			874	822	720	617	515	411	309	257	206	
18	Law[1]	Water	0.333	13.7	17.2	22.0	25.5	28.3	31.8	36.2	38.7	42.3	13.0
18	Law[1]	"Oil"	0.333	13.0	17.8	23.9	29.0	35.0	41.5	49.5	54.5	61.3	12.0
18	Law[1]	Air	0.333	21.0	35.0	64.0	101.5	142.0	203.0	273.0	.....	.....	17.0

				Time in Minutes to Cool from 1252 Degrees Cent. to									
	Rounds			1217	1144	1001	859	716	572	429	358	287	
24x134	Bash[1]	Air	0.183	48.3	77.5	115.0	154.0	250.0	366.0	510.0	.....	.....	45.0

[1]Refer to footnotes (4), (5) and (6) of the text.

of C_3 in equation (4) were calculated and it was found that its numerical value depended not only upon the coolant and the cooling interval, but also upon the surface per unit of volume. Under such conditions the direct evaluation of this constant for even one coolant involves a great deal of work, including such extensive experiments that when completed they make the evaluation unnecessary, for there have been obtained experimentally all required data. For this reason, the results of the calculations referred to are not here included.

Obviously what is needed is to evaluate C_3 in terms of readily determinable factors associated with the surface per unit of volume and the coolant, so that with a cooling curve for the center of one size of the simple shapes immersed in a given coolant curves can be derived by means of simple calculations for various sizes and shapes when quenched into the same coolant.

Without giving in detail the mechanism by which these relations were developed, one feature should be mentioned. With the exception of the first drop in temperature, say for an interval of 20 degrees Cent., the cooling curves for various sizes appeared to closely follow the relations represented by equation (4). More specifically, when deriving time-temperature cooling curves for the center of large sections from constants determined from experiments on small samples it was found that the derived curves were in most cases generally parallel to, but offset at some distance from, curves determined experimentally. The derived curves in practically all cases showed more rapid cooling than was observed directly by experiment, and the magnitude of this difference appeared to increase with the section, and hence with decrease in the surface per unit of volume.

Consider for a moment that heat is first taken away from the surface and an appreciable time elapses before there can be an appreciable drop in temperature at the center. In small sizes (high values of $\frac{S}{W}$) where most rapid cooling is obtained, this difference will be very small, whereas in the relatively large sections (small values of $\frac{S}{W}$) when the surface is far removed from the center, it will be large.

It is extremely difficult to determine the time required for

the first very small temperature drop at the center. Therefore this factor, which will hereafter be called "lag," will be defined for the purpose of this report as the time required to drop a number of degrees equal to 2 per cent of the cooling ranges (equals 17.1 degrees Cent.) for a quenching temperature of 875 degrees Cent. when the coolant is at 20 degrees Cent. Actually the "lag" increases with decrease in the surface per unit of volume, and hence with increase in size of any one of the simple shapes (refer to Fig. 3).

Based on reasoning along this line and a study of the experimental data summarized in the various tables and charts in this report, the following empirical relation was developed:

$$T - x = y\left(\frac{W}{S}\right)^n \qquad (5)$$

in which T is the cooling time from the quenching temperature to any lower temperature (in this report expressed in minutes).

x is the "lag" in minutes; represents the cooling time for an initial drop in temperature equal to 2 per cent of the cooling range.

y is the "time constant."

S is the surface area (in this report given in square inches).

W is the volume (in this report given in cubic inches).

n is the exponent depending only on the coolant; its numerical values are the same as in all previous equations in this, and the preceding report on mass effects, already referred to in the text.

With this equation the time-temperature cooling curves for the center of various sizes of the simple shapes may be derived when the steel is quenched into any ordinary coolant, provided only two pieces of information are available (1), the exponent "n" must be known for the particular coolant under consideration, and (2) there must be available an accurate center cooling curve for some one size of the simple shapes when quenched from any temperature at or above about 720 degrees Cent. into this coolant. In other words, if this exponent and one good cooling curve are available, curves can be derived for the whole ranges of sizes and shapes quenched from temperatures at or above 720 degrees Cent.

Time-temperature cooling curves are not exceedingly difficult to obtain, for even with so-called drastic coolants good results may be secured with ordinary pyrometer equipment and

stop watches if the experiment is carried out with moderately large sections which keep down the center cooling velocities. The value of the exponent "n" can be determined, if not now known, by methods already described,[7] and when once obtained for a given coolant is fixed for the various sizes and shapes and independent of the quenching temperature. There then remain the

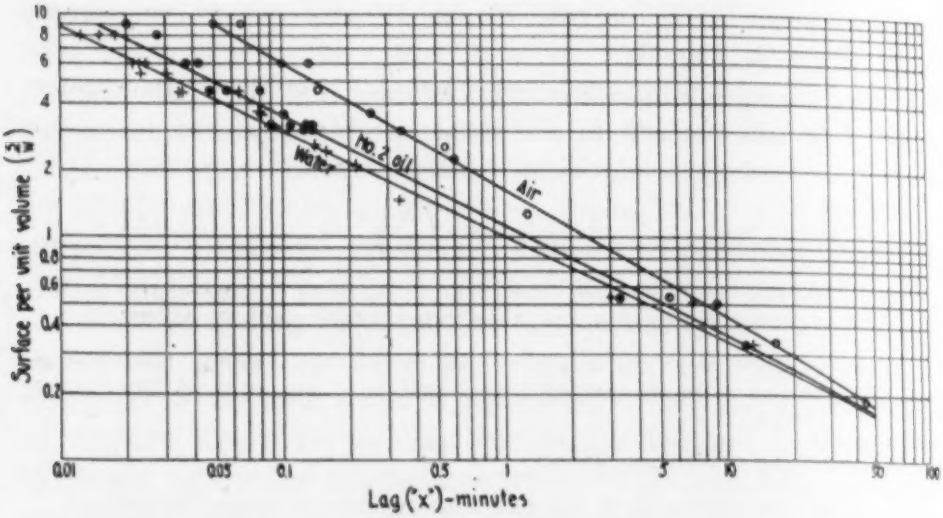

Fig. 3—Relation Between "Lag" in Center Cooling and the Surface Per Unit of Volume of Steel Samples Immersed in Water, Oil or Air.
The Method of Determining "Lag" is Described in the Text.

"lag," x, and the "time-constant," y, for evaluation before the time, T, from the quenching temperature to any lower temperature can be directly determined from equation (5).

A study of the "lag," x, in cooling curves taken when quenching a wide variety of sizes and shapes into water, the oil and air shows that in any one coolant this increases with decrease in the surface per unit of volume; it is greater for a given surface per unit of volume when cooling in air than when quenching in oil and, likewise, greater in oil than in the more "drastic" water quench. As indicated in Fig. 3, in which is shown the relation, plotted logarithmically, between "lag" and surface per unit of volume, the differences between water, oil and air diminish as the size of sample increases (as the surface per unit of volume decreases). This feature again confirms the view, already expressed, that the center cooling of large masses is effected to a much smaller degree by the coolant than small sections, be-

[7]Refer to footnote (1).

cause the surface is far removed from the center and is small in comparison with the volume of metal to be cooled.

No attempt was made to express mathematically the relation between "lag," surface per unit of volume and the coolant, for it is a simple matter to prepare a chart covering these relations by which values of the "lag" may be scaled directly. This "lag" chart, which should be more useful from a practical stand-

Table III

Values of the Time Constant "y" for Various Cooling Ranges in Various Coolants

Coolant	Time constant for cooling ranges beginning at the quenching temperature and ending at the temperature shown (expressed as % of quench-temperature)[1]								
	97.2%	91.4%	80.0%	68.6%	57.2%	45.7%	34.3%	28.6%	22.9%
Water	0.18	0.51	1.02	1.48	1.98	2.53	3.27	3.68	4.40
No. 2 Oil	0.17	0.44	1.04	1.53	2.54	3.97	6.63	9.05	....
Air	0.44	3.04	9.19	17.92	29.25	44.82	65.57	78.22	99.82

[1]For example, the range from 1000-600 degrees Cent., when quenching from 1000 degrees Cent., is given as 60 per cent. (Refer to footnote 3a of the text.)

point than equations, is reproduced in Fig. 4, and for the sake of reducing its size semi-logarithmic coordinates were used.

The "lag" for any size of the simple shapes may be found in ordinary coolants by locating the intersection of the line representing exponent "n" for the coolant with the curve for the surface per unit of volume equal to that of the sample in question. This chart is based on the lines drawn through the "scatter" of points for water, the oil and air in Fig. 3. Each of the lines representing surface per unit of volume in Fig. 4 are therefore based on three points, those respectively for water (n = 1.75), the oil (n = 1.4) and air (n = 1.15). Their exact curvature may, therefore, not have been obtained, but undoubtedly they are drawn very close to proper form because with very slow cooling (n = approximately 1) the lag would be large, so that each of the curves must bend sharply in the direction shown. However, the principles involved in the preparation of this chart are considered of more importance than the numerical values, which will change for different metals.

Since x of equation (5) is now known for any ordinary coolant for which the value of the exponent "n" is available, only the "time-constant," y, must be secured. The solution of equation (5) for y, based on experiments with a variety of sizes and

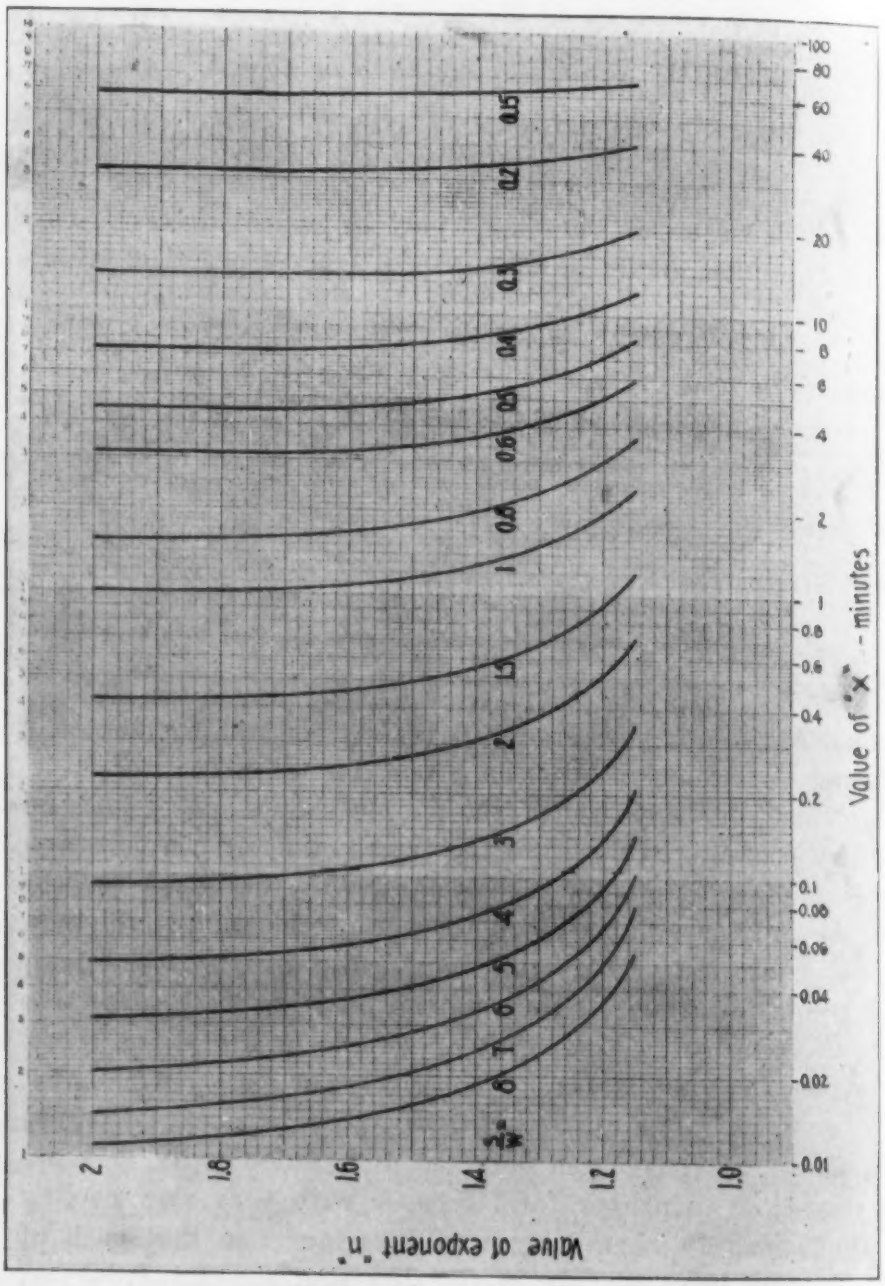

Fig. 4—"Lag" at the Center of Various Sizes and Shapes When Quenched Into Various Coolants. From This Chart the Value of x in Equation (5) May be Determined for Various Coolants and Different Sizes and Shapes of Steel. The Value of the "Lag," x, May be Scaled Directly in Minutes if the Exponent, n, in Equation (5) is Known for the Coolant Considered.

shapes, was carried out, and as shown in Fig. 5, this is dependent only upon the cooling interval, provided the final temperature is expressed as a proportion of the initial (quenching) temperature. Average values for y are given in Table III. The direct appuication of equation (5) may now be considered as all terms except the time T have been evaluated.

For example, consider motionless water at 20 degrees Cent. for which the value of the exponent "n" is equal to 1.75. If a time-temperature cooling curve is available for a sample with a surface per unit of volume of 1 when quenched from, say 875 degrees Cent., the following procedure is used in the derivation of cooling curves for other sizes and shapes quenched from temperatures at or above about 720 degrees Cent.

First, determine from the known cooling curve the lag (x) and solve the equation (5) for the time constant, y, for various cooling ranges, for example, from the quenching temperature of 875 to 800, from 875 to 700, from 875 to 600 degrees Cent., etc.

The values of y obtained for each interval apply to the various sizes and shapes which may be considered.

Secondly, determine from the "lag" chart, Fig. 4, the values of x for the various sizes and shapes for which data are desired. These values are obtained from the intersection of the line n = 1.75 with the respective surfaces per unit of volume of the sizes and shapes to be considered.

Third, to locate the cooling curve, substitute in equation (5) the proper value of x for the size considered, the proper value of surface per unit of volume and the value of y for each of the cooling intervals desired and solve in each case for the cooling time T.

If these values of T are plotted against the final temperature expressed as a proportion of the cooling range, a time-temperature cooling curve will be obtained which will represent the cooling of the particular size and shape considered when quenched from any temperature at or above about 720 degrees Cent.

If this process is repeated for various values of surface per unit of volume, a series of cooling curves will be obtained for the various sizes and shapes quenched into this coolant.

Fig. 4—"Lag" at the Center of Various Sizes and Shapes When Quenched Into Various Coolants. From This Chart the Value of x in Equation (5) May be Determined for Various Coolants and Different Sizes and Shapes of Steel. The Value of the Lag, x, May be Scaled Directly in Minutes if the Exponent, n, in Equation (5) is Known for the Coolant Considered.

The results of computations carried out for air in a manner similar to that described above gave the typical results shown in Fig. 6. This chart, which has been plotted to logarithmic co-

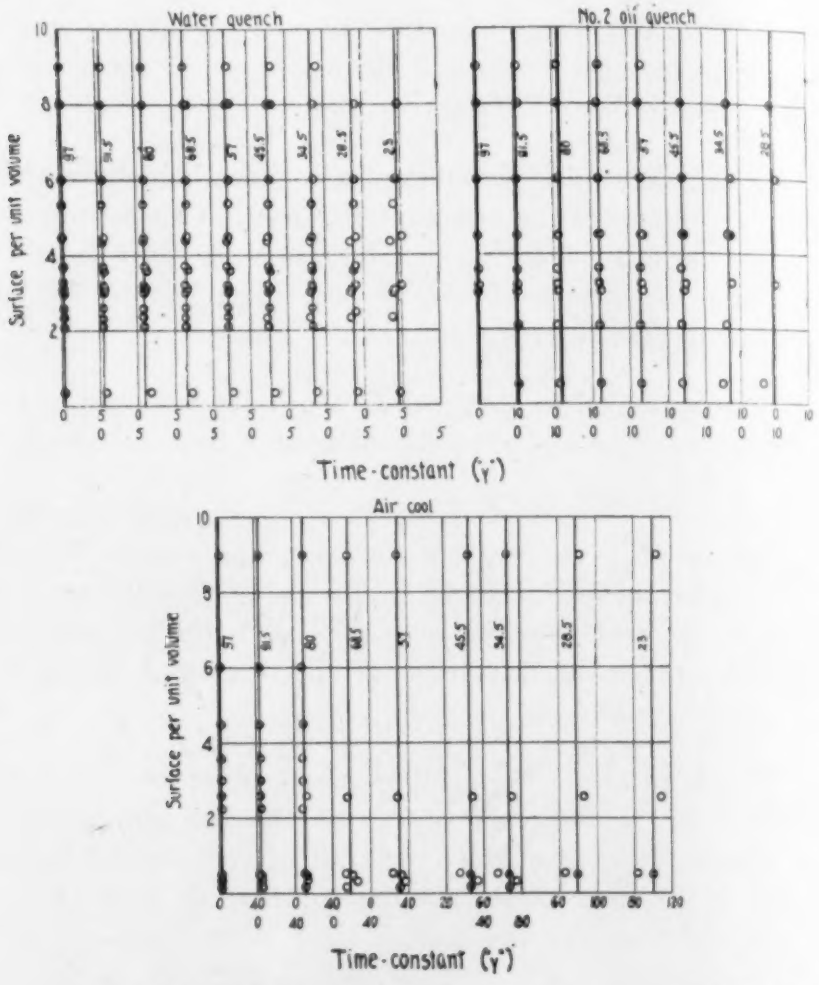

Fig. 5—Relation Between the "Time-Constant," y, for Various Cooling Ranges and the Surface Per Unit of Volume of the Sample.
Numerical Values on Each Vertical y-line Represent the Cooling Range from the Quenching Temperature to a Lower Temperature Expressed as a Per Cent of the Temperature of Quench. (Refer to Footnote 3a of the Text.)

ordinates to reduce its size, is not presented so much to give numerical values as to demonstrate the method of preparation which may be applied to many coolants. It is to be understood that the term coolant here refers to a medium at a particular temperature with a particular rate of circulation or motion; a change in any one of these or other important factors represents a change in the coolant.

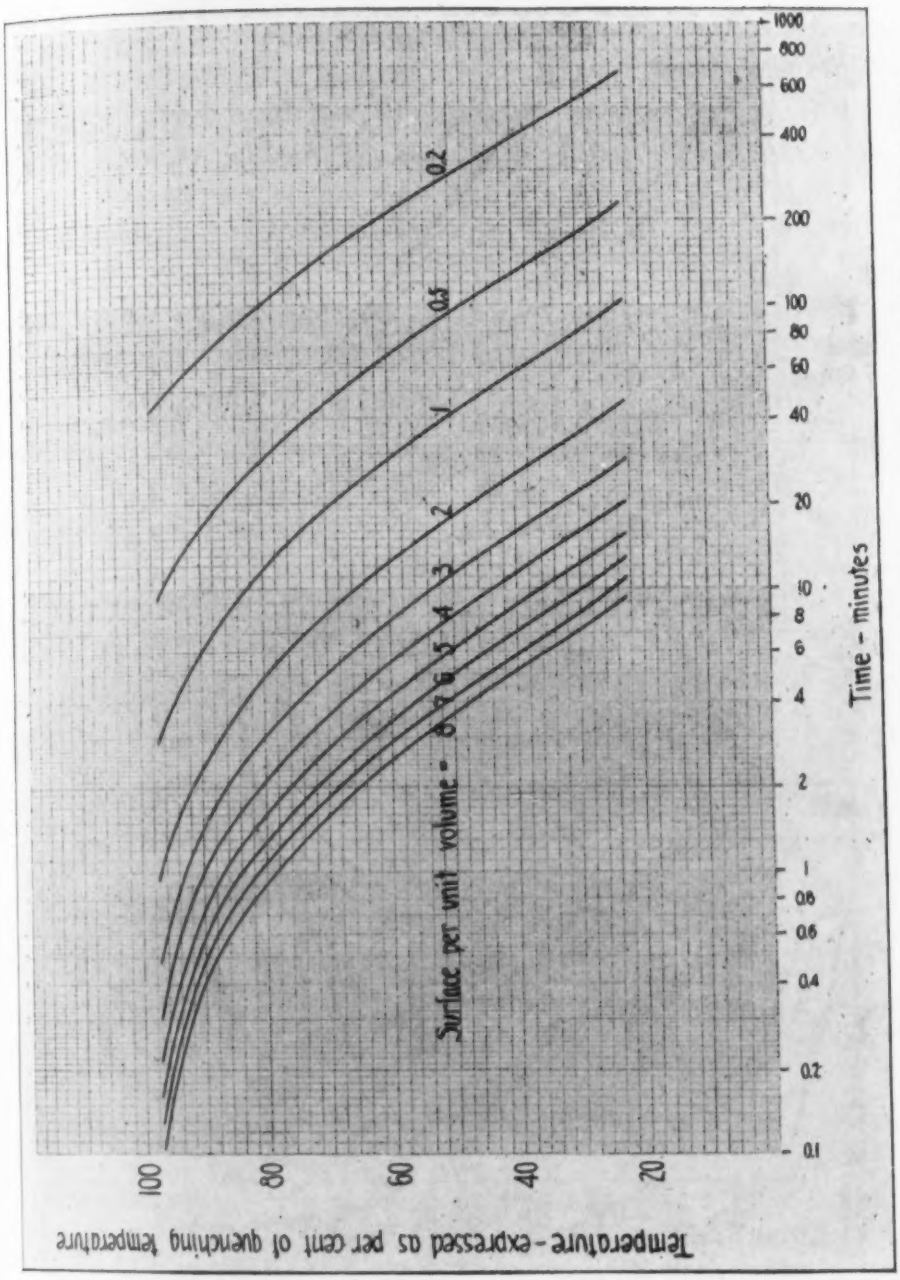

Fig. 6—Derived Time-Temperature Cooling Curves for the Center of Different Sizes and Shapes Cooled in Air. Semi-Logarithmic Coordinates Were Used to Reduce the Size of This Chart. Note That the Sizes and Shapes are Indicated by the Values of Surface Per Unit of Volume and That All Temperatures Are Expressed as a Proportion of the Quenching Temperature. (Refer to Footnote 3a of the Text.)

IV. General Discussion and Summary

Admittedly, the described methods and relations are empirical, for they are not based on the fundamental constants of materials, but upon direct experimental determination of cooling times under a variety of conditions. Their accuracy or that of similar computations for other coolants depends upon the accuracy

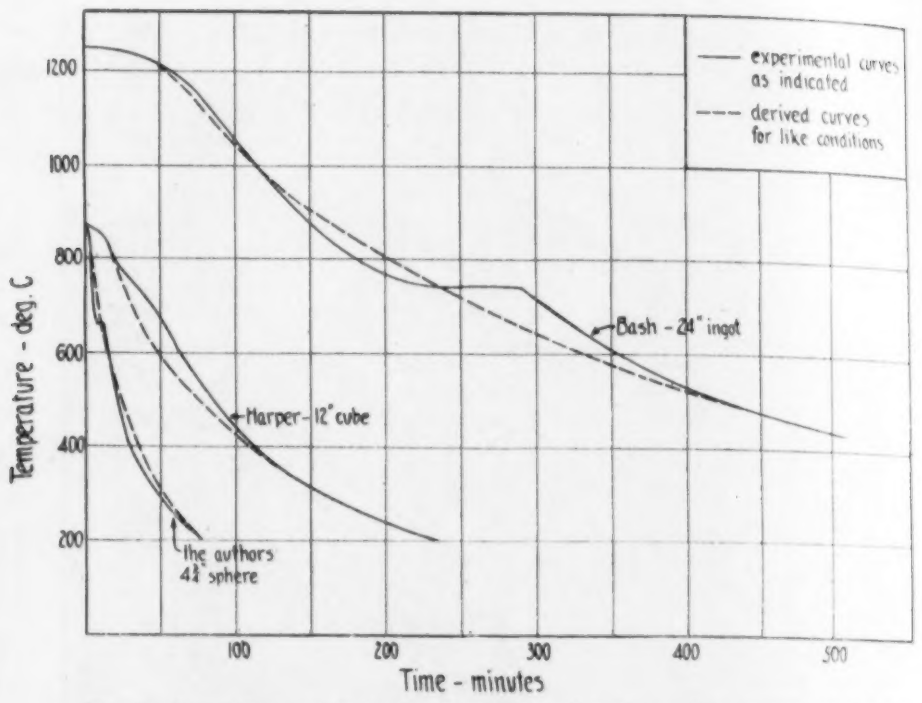

Fig. 7—Comparisons of Derived and Experimental Air Cooling Curves for the Center of Various Sizes and Shapes.

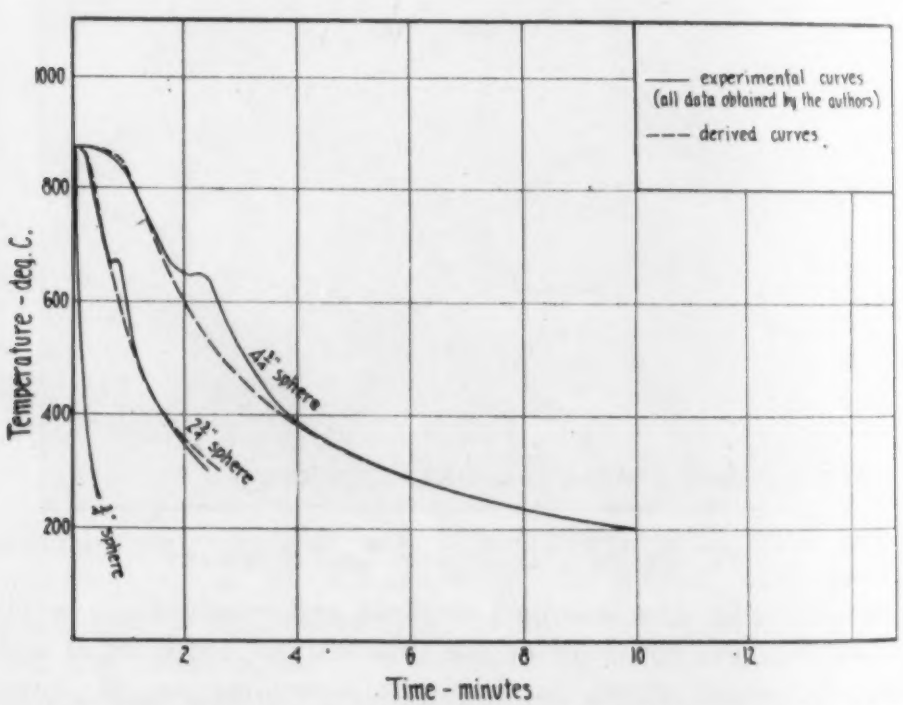

Fig. 8—Comparisons of Derived and Experimental Oil Cooling Curves for the Center of Various Sizes and Shapes.

Some of the Properties of the Oil Used in These Experiments (Called No. 2 Oil) Are Given in the Publication Referred to in Footnote (2) of the Text.

attained in the experiments upon which they are based. For this reason, it would be unwise, under ordinary conditions, to base calculations for a given coolant on a single cooling curve. A safer course would be to secure curves for at least two widely different sizes and shapes and in both cases to demand at least two consistent experiments.

However, with accurate basic data from which to make cal-

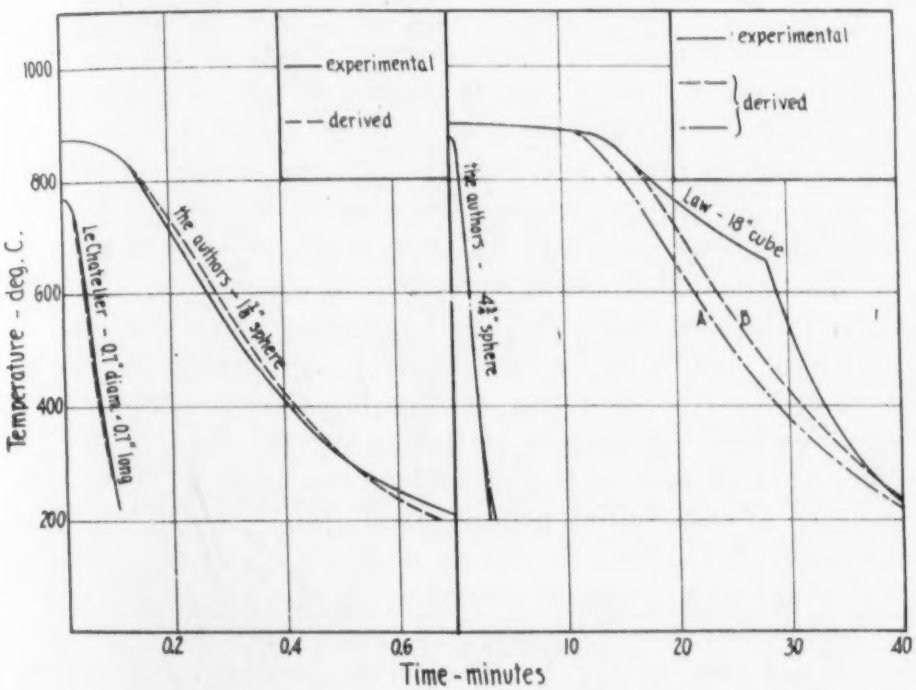

Fig. 9—Comparisons of Derived and Experimental Water Cooling Curves for the Center of Various Sizes and Shapes.
LeChatelier's Cooling Curve Obtained from Rev. Met. Mem. 65, Part 1, 1904, pp. 473-493.

culations, cooling curves will be obtained which are close to those determined experimentally and more representative of the actual cooling than curves derived at this time from purely theoretical considerations, because the latter include assumptions and approximations of the values of certain physical constants of materials which are not now accurately known. This has been fairly well established.

Comparisons of derived curves with those determined experimentally for different sizes and shapes quenched in water, oil or cooled in air are given in Figs. 7, 8, and 9. As far as was practicable these comparisons were made with results of other

investigators and show that direct experimental confirmation is available for the described empirical relations covering a wide range in conditions. Naturally the derived values do not closely check all published results for like quenching conditions, but agreement is obtained with representative experimental data other than that obtained by the authors.

It will be observed in Figs. 7, 8, and 9 that there may be appreciable variations between the derived and experimental cooling curves in the zones of thermal effects of transformations. There is no reason why these thermal effects should not be taken into account in determining the time-constants for a given coolant so that a closer approximation will be obtained throughout the entire cooling range, particularly for large masses. This was not done by the authors because the magnitude and position of the transformations vary with different steels, and, as already stated in this report, there were variations in composition of the steels from which the large and small specimens were prepared. The important feature to be emphasized is the similarity, in a given coolant, between the center cooling for various sizes and shapes, which enables a resolution of cooling curves into two major components, both related to the surface per unit of volume of the sample: (1) an initial period called "lag," which represents 2 per cent of the cooling range, and (2) thereafter the typical time-temperature changes characteristic of the particular coolant.

Attention should be called to Law's water cooling curve for an 18-inch cube in Fig. 9. The derived cooling curve for such a cube, based on the average "lag" from Fig. 3, is shown by the dotted line A in Fig. 9, which is generally parallel to, but offset from, the experimental curve given by Law. In other words, the major difference between the two is due entirely to the initial period or how soon after immersion in the water an appreciable center cooling begins. Comparison of Law's water cooling and oil cooling curves for the same cube shows the "lag" to be greater in water than in the less "drastic" oil quench. There is considerable evidence from various sources that this is improbable or at least associated with some unusual or not fully defined conditions in his experiments. If the actual "lag" scaled from Law's curve is used in place of the average lag for this size of cube given in Fig. 3, the dotted line B in Fig. 9 is obtained and closely agrees with the experimental values.

It should, perhaps, be pointed out that for large masses small differences in the surface per unit of volume result in relatively large changes in the "lag," due to the fact that the relation between these two factors is such that when plotted to logarithmic coordinates a straight line is obtained, as in Fig. 3. In other words, a supersensitive set of conditions are encountered, and unless these are accurately defined when experimenting with large masses, appreciable variations are to be expected in duplicate cooling curves, which may be generally parallel to, but offset at, some distance from each other.

Special attention should be called to the fact that the values of the exponent "n" of equation (5) are the same as and apply equally well to the relations between mass and cooling velocity previously described[8] as to the time-temperature relations dealt with in this report. This adds material weight to the validity of the described relations.

Another feature of interest lies in the relation between this coolant constant, n, and the "lag." Were it not for the fact that it is impracticable at this time to attain the desired degree of accuracy in the experimental work, the value of "n" for a coolant might be determined directly from Fig. 4, after measuring the lag in the manner described when cooling some one size of the simple shapes in that coolant.

Aside from the determination of cooling times in typical coolants, the methods outlined make possible a correlation of data, irrespective of size (of the simple shapes) and quenching temperature (when at or above about 720 degrees Cent.), which heretofore has been exceedingly difficult, if not impracticable.

There follows a summary of the main features of the described experiments.

1. In a given coolant the center of a sample of given size and shape cools in equal times to equal proportions of the cooling range. Thus, if temperatures are expressed as a proportion of the interval between the quenching and coolant temperatures, results obtained are directly applicable to any quenching temperature (when above the transformations).

2. When quenching various sizes of the simple shapes into a given coolant, the center cooling time minus a factor called "lag," is inversely proportional to the surface per unit of volume

Footnote. Refer to footnote (1).

raised to some power greater than 1 and less than 2. If T = cooling time, S = surface area, W = volume, n = a constant depending upon the coolant, y = the "time-constant" which, for a given coolant, depends only on the cooling interval considered, expressed as a proportion of the cooling range, and x = "lag," which is the time required for the center to fall 2 per cent of the cooling range, then these relations may be represented by the equation

$$T - x = y\left(\frac{W}{S}\right)^n \qquad (5)$$

3. "Lag," which refers to the time required for the temperature at the center to drop 2 per cent of the cooling range, increases with the size of sample and, hence, with decrease in the surface per unit of volume. It is greater for a given size and shape of sample in slow coolants, such as air than in oil, and, likewise, greater in oil than in the more "drastic" water quench. While an equation can be derived, giving "lag" in terms of the coolant exponent, n, and the surface per unit of volume this has not been included in this report; instead a "lag chart," Fig. 4, was prepared from which values may be scaled directly for various sizes and shapes quenched into various coolants, provided only the coolant-constant, n, is known.

4. From this chart and equation (5), above, time-temperature cooling curves may be derived for the center of various sizes and shapes quenched from various temperatures into ordinary coolants, provided only the coolant constant is known, and there is available a cooling curve on some one size quenched into this coolant from some one temperature. It is, however, generally safer to base such calculations on determinations from several sizes if reasonably good accuracy is to be obtained.

Acknowledgments

Acknowledgment is made to T. E. Hamill, laboratory assistant, for his assistance in carrying out the experimental work, and to J. F. Harper of the Allis Chalmers Manufacturing Company, Milwaukee, Wis., for supplying prior to publication the cooling curves on the 12-inch cube.

Discussion

R. S. Archer: We all appreciate what a task the authors have undertaken in this analysis of cooling rates and that they have done an immense

amount of careful work. There are however one or two technical points I wish to mention and then a philosophical point.

First, a question: I understood Mr. French, in referring to Law's experiment, to say that Law had found a smaller lag on oil quenching than on water quenching, and that Mr. French would expect a smaller lag on water quenching because the rate of cooling is faster. Is that correct?

H. J. FRENCH: Law did not consider this factor called "lag" but by comparing his oil and water cooling curves you will find that the time required for a drop of 2 per cent in the cooling range, which we have defined as "lag", is smaller in the oil quenching than in the water quenching.

R. S. ARCHER: I may not understand just what this lag means physically, but it would seem to me that the faster the rate of cooling as a whole, the greater would be the difference in temperature between surface and center at any given time.

H. J. FRENCH: That is correct.

R. S. ARCHER: Well, then, we are in agreement on that.

The second technical point concerns a line of evidence from an entirely different field. It may seem quite far from foundry practice in aluminum to hardening steel, but we have encountered some of these questions regarding cooling rate. In the process of refinement or modifying of aluminum silicon alloys, it becomes fairly important to know the time required for a pot of molten metal to cool from a certain temperature to the pouring temperature. In connection with Mr. French's remarks about the relative constancy of air cooling, it may be of interest to mention that we have found an important difference in the time required to cool from, say, 1400 to 1280 degrees Fahr., depending on the weather. This work is carried out inside the foundry, where the atmospheric temperature only varies a small amount as compared with the outside temperature, but when the outside temperature varies, say, 40 degrees Fahr., we find a difference in that cooling rate that is important to us, and more than we expected. The difference in the temperature of the air inside the foundry was probably not over 20 degrees Fahr.

H. J. FRENCH: What percentage would that difference be in your case? (in cooling rate.)

R. S. ARCHER: I do not recall the figures, but I would say that it would be something of the order of 25 per cent.

H. J. FRENCH: We found greater variations in the oil and water quenching than in air cooling. I think that you may have misunderstood the remarks which I made. I did not say that the variations in air cooling were small. I said they would be relatively smaller than we ordinarily get in different plants with the oils and possibly also water.

R. S. ARCHER: We were surprised to find how large this was. We rather hoped that we could establish definite cooling times for the various sizes of crucibles and be done with it, but it seems that the weather has quite an effect on it.

Finally as to the philosophical point. My understanding is that all this work is directed ultimately toward the prediction of heat treatment effects in pieces of steel of various sizes. And the question occurs to me, as I sup-

pose it certainly has occurred to the authors, whether this amount of analysis pays in reaching those practical results. Whenever we encounter a very complex problem and a large number of variables, we eventually reach a number of variables so great that an empirical solution in each case is easier and much more certain than a calculated solution based on an analysis of this kind.

There is another factor involved (if that is the object of the work) which has not been discussed today, although I presume that it too has been considered, and that is as to whether cooling rate alone is the major factor in determining the physical changes in steel. We know that pressure, for instance, plays an important part in physical transformations, that the formation of martensite is accompanied by a volume increase, therefore that an increase of pressure should tend to retard that change. For that reason I should think that in pieces of different sizes, the differences in pressure conditions might have an effect on the results which would be large as compared with the differences in cooling velocity, and that the differences due to pressure variations might be even more difficult to predict than the cooling rate itself. I wonder if the authors have considered this and if it has been found that these other variables are really minor as compared with the cooling rate; that is, if it seems that the calculation of cooling rate alone is sufficient to enable us to predict fairly accurately the result of a given heat treatment on a piece of a given size.

H. J. FRENCH: In reply to your question, Mr. Archer, your premise is only partly correct. It is true that we have given considerable attention so far to the microstructure, hardness and properties of the steels being quenched. However, our primary object in carrying out work of this sort is not directed toward the steel, but toward a study of coolants. We are primarily interested in the mechanism of quenching, and could we conveniently create graded coolants today as we would like we could undoubtedly improve the properties produced in steels.

In order to study coolants we must consider the time-temperature relations in cooling, preferably not at the center, but at the surface. However, I can fairly state that the difficulties encountered in duplicating results at the center of regular sizes and shapes are sufficient for the average investigator. One of the main reasons for undertaking this survey which was reported this morning was to give us some general idea when we obtained a cooling curve at the center of the specimen, whether the conditions were anywhere near right. We have found that many variables, even with care in the laboratory, affect to a marked degree the cooling curves which were obtained. In order to arrive at a satisfactory base from which to work, it therefore seemed desirable and necessary to make such a statistical study as we have made in this paper. Our ultimate object in the study of temperature distribution during cooling and particularly the changes in temperature with time at the surfaces of steel specimens, because it is the surface of the metal which is in most direct contacts with the coolant or its products. By the entire procedure we hope to learn more about the mechanism of quenching and coolants in general, rather than the properties produced in the steel alone.

With reference to your comments on cooling rates in relation to aluminum

foundry practice it seems to me that the large differences in properties of the solidifying metal arising from what you believe to be only small changes in temperature of the surrounding air might more accurately indicate an extremely sensitive condition on the part of the aluminum alloy rather than be considered as evidence of any large differences in the air.

The fact that pressure variations within the metal during cooling may influence the final properties has long been recognized or at least suspected. However, these pressure variations are associated with variations in the cooling rates. It therefore would seem of highest importance to study the time-temperature relations in cooling which, through the constitutional changes create or modify the pressures you speak of.

G. H. WRIGHT: I would like to ask Mr. French if he made any physical tests on his theoretical quenching temperature when applied to larger masses, the object being to see if he could get equally good results, especially with respect to strength and elastic properties.

H. J. FRENCH: I do not believe I quite understand your question. We have not made any physical tests other than hardness determinations on the quenched samples and in most of the large sections we have not made these hardness tests, being primarily concerned with the method of comparison, rather than the numerical values for constants or the constituents and the properties of the steel. Did I understand your question?

G. H. WRIGHT: Correct.

O. Z. KLOPSCH: It might be mentioned that Law gave the tensile properties throughout the 18 inch cubes which he quenched, These results showed that the tensile properties at the center were very nearly the same for either water, oil or air cooling. I think they varied in the neighborhood of only 10,000 pounds per square inch whereas at the surface they varied from 40,000 to 50,000 pounds per square inch.

W. J. MERTEN: I would like to ask Mr. French whether he found any difference in the curves when quenching the steel in an agitated liquid as is the general procedure in heat treating plants.

H. J. FRENCH: That is a rather mean question, Mr. Merten, because of the fact that we have plenty of difficulties in checking curves for supposedly duplicate experiments. We believe we have found considerable difference, but I would not want to make a positive statement to that effect. If the agitation or coolant velocity is high enough, there is no question about the existence of real differences in cooling rates but those differences are more or less masked at the center. In surface cooling curves which have so far been obtained there are very large differences, and other interesting features which we are not prepared to discuss at this time.

MR. MERTEN: Would not such agitated coolant entirely change the percentage L, or percentage value of N?

MR. FRENCH: Yes, I mentioned before that all of these constants were dependent upon the composition of the coolant, the rate of agitation, and temperature, etc. When I say "coolant" I refer not only to a particular composition as for example, water, oil or air, but to a particular temperature and rate of agitation as well.

L. A. LANNING: I would like to ask if you found any differences in cooling rates due to the surface finish of the specimen?

H. J. FRENCH: Yes, we have. I do not know that I speak of exactly the same thing that you do, but I can give you a specific example of what I mean. If we take certain oils and blend with them other oils, cooling ordinary steel samples, we find an increase in the cooling velocity in the neighborhood of 700 degrees Cent. when quenching steel samples from 875 degrees Cent. Now, if in place of using a steel sample with a machined finish or a ground finish, we nickel-plate, chromium-plate or silver-plate this sample, we do not necessarily get, from measurements at the center, the same increase in cooling velocity from the blended oils. The character of the surface undoubtedly does have, at least in some cases, a marked effect, but we do not know what the limiting conditions are. I could not answer your question if you had put it into this form: "Does a polished or lapped surface give you a different cooling than a rough machined surface?"

However, I may say that we believe the differences in this case would be of a different order of magnitude, than the differences of which I previously spoke when referring to quenching in various oils.

The determination of the effects of surface condition on the cooling requires special equipment and precautions experimentally for it must be remembered that with ordinary methods of heating and quenching we get oxidation both in the heating and the transfer of the metal to the quenching bath and we no longer have the surface conditions we started with.

DR. J. A. MATHEWS: I would like to ask Mr. French if thermal conductivity due to variation of carbon content, or more especially to the addition of alloys, has anything to do with the results?

H. J. FRENCH: It may have, Dr. Mathews. In all these cases we have to go more nearly to extremes in order to develop, with our present methods of test, the importance of such factors. If, in place of steel samples, we use copper, we get very much higher rates of cooling for the same size quenched in the same coolants. As far as our tests have gone, the very low carbon steels cool somewhat more rapidly than the higher carbon steels, but the differences are not of the order of the differences when a change is made, for example, from ferrous products to copper. We have made tests on high speed steel samples, certain structural alloy steel samples, and certain alloy tool steels, notably the higher carbon—low tungsten varieties and all of these fall in line pretty well with the cooling curves which we have obtained on the carbon steels. There may be differences, but they are very hard to detect with certainty by our test methods and are not of a very large order.

Authors' Closure

Since presentation of this report an air cooling curve taken by Basa some years ago on a 45 inch ingot has been obtained through J. F. Harper of the Allis Chalmers Manufacturing Co., Milwaukee, Wisconsin. It is given in the figure below and in comparison with the various curves contained in the

(Continued on Page 906)

GRAPHITIZATION AT CONSTANT TEMPERATURE

By H. A. Schwartz

Abstract.

The preparation of this article was motivated mainly by a desire to demonstrate that the graphitizing reaction is not the erratic and poorly understood phenomenon which some metallurgists believe it to be, but rather, that it is the expression of the operation of entirely definite natural laws, as well established as any in physical chemistry. It is further desired to emphasize the fact that, although these laws are simple in principle, the physical constants involved are functions of so many variables that their application becomes distinctly complex and not to be safely undertaken except after a thorough knowledge of the circumstances.

The material presented consists of a mathematical analysis of the data of graphitization. As a result of this treatment, a means for the laboratory determination of graphitizing rate, as a physical constant of any given hard iron, is outlined. This method is new, so far as the author is aware, and constitutes the only practical application, here given, of the theoretical principles considered.

It is demonstrated that the rate of graphitization is determined by the rate at which carbon can migrate in iron. The progress of graphite formation with time is shown to be an expression of the changing migratory distances, and concentration gradients produced by the reaction.

This demonstration, also, is believed to be new. The procedure by which the mathematical characteristics of the observed graphitization curve are used to determine the character of the physico-chemical processes occurring is also, perhaps, sufficiently unusual, to possess interest for the theoretical metallurgist. The writer does not recall any other similar problem which has been solved by this method of attack.

Reference is made to the range through which the graphitizing rate varies in commercial material. The effect of silicon on this constant is discussed. For a variety of reasons, none of the other variables which affect this constant have been considered, and the reader

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is cautioned against any belief that the cumulative effect of the many variables involved can be summed up from assumptions as to their effect separately. Partly on account of these theoretical perplexities, and also because it was desired to focus the attention upon metallurgical principles only, nothing in the nature of operating data has been included. The malleable metallurgist may, perhaps, find here an explanation of some of the fundamentals of his process, but no suggestions as to desirable or objectionable practices.

MANY experimenters have examined the phenomenon of graphitization during the past ten or fifteen years. Very generally they were interested in the conditions of time, temperature, and carbon concentration at equilibrium. Many workers, as, for example, White and Archer (1),[1] gave data as to the progress of graphitization with time, but, in general, such data were inserted mainly as evidence that the reaction had ceased under given conditions. A few experimenters, of whom White and Gladhill(2) may be considered typical, were concerned with the effects of variables upon the time to attain equilibrium.

Hayes, Diederichs, and co-workers(3) have considered the circumstances under which graphitizing time may be reduced to a minimum without elaborating upon the effects of variables other than temperature on this time. Heyn(4) and the present author(5) have shown graphically the progress of graphitization with time, but made no effort to elucidate the significance of the form of curve observed.

An exposition of the characteristics of the curve correlating graphite formation with time is deemed to possess considerable importance. It will be shown to permit of conclusions regarding the theory of graphitization, and furnish a basis for a precise method of measuring graphitizing rate. Such a study will also be of significance as applying to the general problems of stable and metastable equilibrium. In addition, it may be useful to the metallurgist who is not a specialist in the malleable castings field, in that it will put at his disposal information calculated to demonstrate that graphitization follows a perfectly logical system of natural laws, and cannot be influenced in rate by methods not in harmony with these laws.

[1]The figures in parentheses have reference to the selected bibliography appended to this paper.

The present paper is prepared from these view points and advisedly avoids any references to causes affecting graphitizing rates which are not already within common knowledge.

General Considerations

The present discussion is limited to a study of the graphitizing reaction at constant temperature in the interest of simplicity. Some preliminary studies have indicated that the progress of the reaction at falling temperatures, as in practice in the later stages of "annealing," does not yet lend itself sufficiently to generalizations to warant its inclusion herewith. The experimental procedure underlying the investigation consists of the theoretically simple process of heating white cast iron of known history and composition for various periods of time, quenching, and determining the graphitic and agraphitic carbon, and the microstructure if required. We use, purposely, the term agraphitic, suggested by Dr. H. M. Howe, to designate that carbon not present as free graphite, in order to avoid any assumption as to whether such carbon is in solid solution as such, or as cementite, or is present as free cementite.

A detailed description of the method of experimentation is here omitted in the interest of brevity. Suffice it to say, that the possible errors due to fluctuations of temperature, decarburization of specimens, sampling, and analysis have been very carefully considered, and minimized, as far as possible, by the adoption of all the precautions which many years of experience have suggested as desirable and practicable.

The work was primarily confined to temperatures above A_1, although some information was gathered from which to draw conclusions as to the identity or otherwise of the mechanism of the reaction above and below A_1. Since the problem has, in some of its aspects, engaged the attention of the writer and his earlier co-workers for ten or fifteen years, it is difficult now to assign proper credit to each member of the metallurgical staff of the National Malleable and Steel Castings Co., who has contributed materially to the subject.

The recent intensive study of the problem was begun by Dr. M. M. Austin, now of the University of Illinois, to whom, also, we owe the suggestion of investigating the facts as to number of carbon nodules. Upon Dr. Austin's retirement from service in the

Research Department, the analytical and heat treatment work was taken up by Mrs. Anna Nicholson Hird, who has gathered the major portion of the data. H. R. Payne carried on all the metallographic work required. G. M. Guiler contributed to the chemical end of the problem, and he and H. H. Johnson aided materially in checking the mathematical theory involved.

Especial thanks are due to Arthur S. Hathaway, lately Professor of Mathematics at the Rose Polytechnic Institute, for his solution of one of the fundamental mathematical problems involved.

Since no useful purpose would be served by their inclusion, the hundreds of determinations made incidentally to this study will be omitted, except insofar as they furnish the basis for the various graphs or require particular reference. The mathematical treatment being new, cannot be omitted, but is largely relegated to the Appendix, where it may conveniently be ignored by the non-mathematical reader, while continuing available to the more thorough student.

Chemical Data

In Fig. 1 are shown four typical graphitization curves. The ordinates represent the degree of completion of graphitization; i. e., the percentage of the carbon available for graphitization which has been precipitated. The carbon available for graphitization is the total carbon of the material less the agraphitic carbon content of the stable solid solution at the temperature and silicon content chosen. For data on the latter point, the reader is referred to previous publications from this laboratory(6),(7).

The abscissæ represent hours and are plotted to a logarithmic scale. The four curves represent two different irons at each of two different temperatures. The materials differ moderately in carbon content, as between 2.60 and 2.25 per cent, and were selected primarily because they differ about as widely in graphitizing rates as any materials which would be encountered in commercial practice. They differ in silicon, but it may be stated here that this is not the sole reason for the difference in graphitizability.

It will be noted that under the scheme of coordinates here chosen, the four curves can be brought into practical coincidence by shifting them horizontally. A few minor discrepancies will here creep in, due to the fact that the solubility of carbon in the two systems is a function solely of temperature (for a given silicon

content). This solubility, therefore, constitutes a different percentage of the total carbon as the temperature and total carbon vary. The variation, due to this consideration, is, however, relatively small, and will occasion no confusion if the reader will bear in mind that some correction for this factor is admissible.

In Fig. 2 the four curves of Fig. 1 have been averaged by

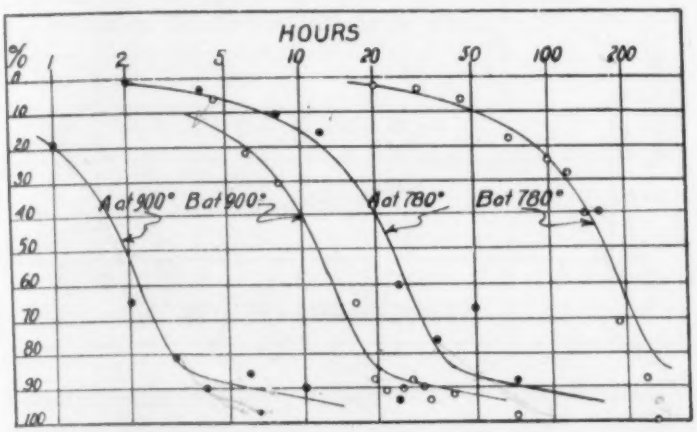

Fig. 1—Time Versus Degree of Completion of Graphitization Above A_1.

bringing them into coincidence by a shift which arbitrarily calls time unity, where graphitization is one-half completed. The logarithmic time scale has been abandoned for a uniform one. Be it remembered that they could have been equally as well superimposed by selecting any degree of completion of the reaction and arbitrary time designation instead of 50 per cent and unity. The choice is merely one of convenience. We may thus draw a conclusion:

I. All graphitization curves are alike when plotted to ordinates representing graphite formation, as a percentage of the possible total; and time, using as a unit that required for the completion of half (or any other constant fraction) of the total reaction. An exception arises when the conditions so vary that the graphitizable carbon corresponding to the saturated metastable solution does not constitute the same fraction of the total graphitizable carbon.

In Fig. 3 is plotted a similar curve for one of the same metals graphitized at a temperature below A_1.

Certain other chemical data requisite for the development of

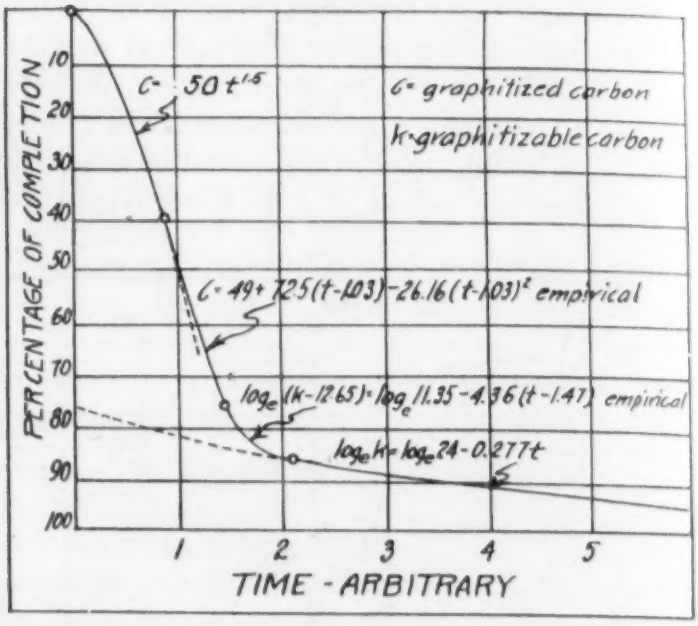

Fig. 2—Time Versus Degree of Completion of Graphitization Above A_1.

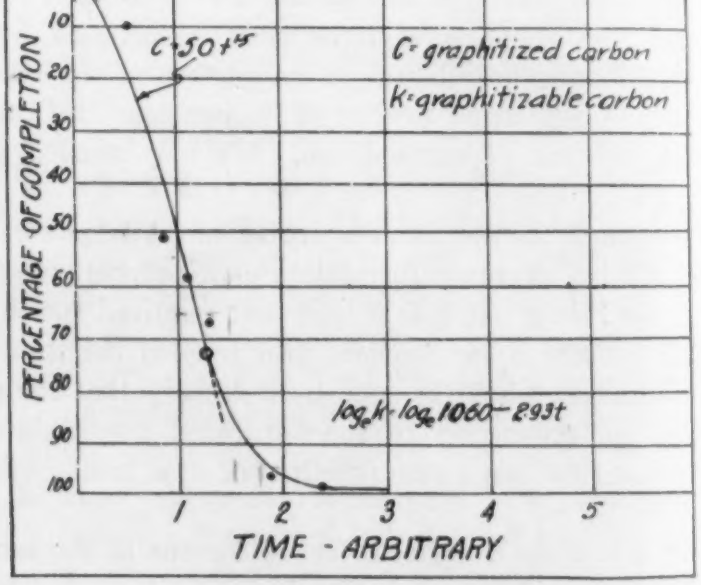

Fig. 3—Time Versus Degree of Completion of Graphitization Below A_1.

this thesis will be alluded to in connection with later developments of the subject.

Metallographic Data

Counts of the number of temper carbon nodules per unit area were made in a number of series of experimental heat treatments on specimens removed after remaining for various times at a given temperature. The number of nodules per unit volume may be deduced from such a count, and a graphite determination by means of the equation

$$MN^2 = 16\ m^3 \qquad (1)$$

whose derivation will be found in the appendix. Where M is the graphite content, N the number of nodules per unit volume, and m the number per unit area in a random plane.

While the results of such counts are somewhat erratic in different fields, and, at best, difficult, still it could be shown that if many fields be counted and specimens of a number of heat treatments are available, the total number of nodules in a given volume does not either increase or decrease materially at any time from that when only sufficient carbon has precipitated to permit a reasonably accurate count up to the time when equilibrium is attained. The assumption seems warranted, therefore, that graphitization proceeds by an increase in size rather than in number of carbon nodules.

The very interesting problem of what determines initially the point at which free carbon forms in the metallic mass is here dismissed without consideration. The laws governing the number of such spots have received some study. The problem is extremely complex, and it may well be neglected here as forming no part of our present thesis. The determining factors lie both in the chemical and other characteristics of the metal, and in the specific heat treatment.

The initial stages of graphitization are represented by micrographs in Fig. 4 and 5. The essential feature of the former is that at this intermediate state the structure consists of nodules of carbon surrounded by zones of solid solution in which no cementite exists. These zones are embedded in a matrix of cementite and solid solution, which, in general, is similar to the structure of the original hard iron when quenched from a similar temperature. The zones and nodules, while not actually spherical, may be con-

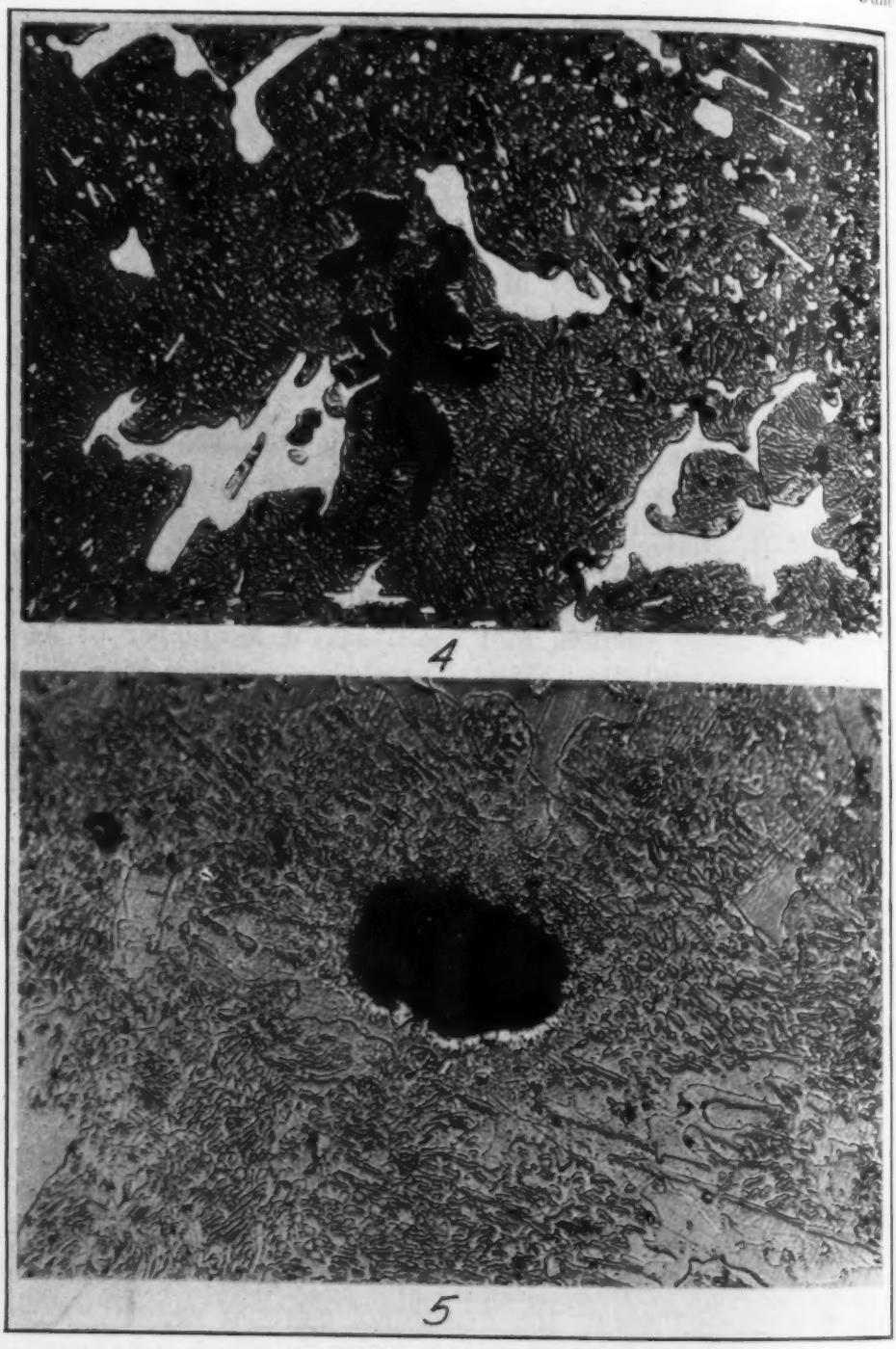

Fig. 4—Graphitization at Constant Temperature. Formation of Free Carbon at 900 Degrees Cent. The Irregular Butterfly Shaped Module of Free Carbon Surrounded by Pseudo-Martensitic Solution. The White Cementite is Largely Destroyed in Region Surrounding the Carbon. Note the absence of small Cementite Grains near Carbon. The Small Black Nodules are Troostic and Not Free Carbon. Magnification 500 X.

Fig. 5—Graphitization at Constant Temperature. Formation of Free Carbon at 740 Degrees Cent., Showing a Rounded Black Nodule of Carbon surrounded by Ferrite in which are Embedded Spheroids of Cementite. The Massive Cementite of Dendritic White Structure Persists. Areas near the Carbon have relatively Little and Finely Spheroidal Cementite. Distant areas show Laminae of Cementite and Larger Quantities. Magnification 500 X.

sidered equiaxed, and so distributed that the mean diameter of many zones or many nodules is the same in every direction; i. e., the structure is mathematically equivalent to a series of spheres of carbon occupying the centers of spheres of solid solution which, in turn, are enclosed regularly in a heterogeneous system of cementite and solid solution.

Fig. 5 differs from Fig. 4 in that the structural entity first disappearing is the eutectoid cementite, the eutectic cementite being but partially removed at the same time. There thus result spherical areas in which the pearlite is replaced by ferrite, but through which the more massive cementite still persists.

From the metallographic data we may for the present limit ourselves to the conclusion that—

II. Graphitization proceeds by an increase in size rather than of number of carbon nodules.

Discussion of Data

Returning now to the curve of Fig. 2, we find it possible to determine empirically the equations of this curve. As a matter of fact, there are four segments of the curve, each of which must be treated separately. From the origin to about 50 per cent of the total graphitization the equation is of the form

$$c = at^{1.5} \qquad (2)$$

where c is the precipitated carbon and t the time, a being an experimental constant. From about 76 per cent to about 85 per cent completion, and from 85 per cent on, the curve is of the form

$$\log_{10}k = \log_{10}k_o - bt \qquad (3)$$

where k is the unprecipitated carbon, t the time, and b and k_o experimental constants. The values of b and k_o are, however, different in the two segments. The segment from 50 per cent to 76 per cent is neglected for the present.

Now it can be shown (see Appendix) that equation (2) represents the rate at which carbon will flow, at a constant gradient through a hollow spherical shell to a central spherical nucleus if the shell constantly enlarge its outer diameter in the same proportion as the diameter of the carbon nodule increases by this migration.

If now we assume that the even distribution of carbon nodules

has placed them at the corners of cubes having a parameter of 2 l, then there will be available for deposit in each nodule the graphitizable carbon in a volume of 8 l^3. When the spherical mass surrounding the nodule has attained a radius of 2 l the spheres around adjacent nodules will interfere. The volume of such a sphere is

$$\frac{4}{3}\ \pi l^3$$

hence, the cementite in

$$\frac{\pi}{6}$$

times the total mass is destroyed when such interference occurs.

If we assume the spherical zone to have no available carbon remaining in the sphere, 52 per cent of the available carbon has then been deposited. However, the spherical zone is in equilibrium at the inner surface with carbon, and at the outer with cementite.

If k_{cm} and k_{gr} represent the solubility of carbon in the metastable and stable system, it is shown in the Appendix that the mean carbon concentration in such a sphere is

$$k_{gr} + \frac{21}{26}\ (k_{cm} - k_{gr}) \qquad (4)$$

There is thus available for graphitization four-fifths (about) of the carbon which would be available if the sphere were saturated austenite throughout. In the present case this would average 23 per cent of the total graphitizable carbon. Instead, therefore, of the original law terminating automatically with 52 per cent of the reaction complete, it will terminate sooner; i. e., at about 43 per cent.

It has been possible to explain the segment of the curve from 50 to 76 per cent completion by considering the decreasing areas of cementite bearing metal in contact with the cementite free spheres. When this calculation is made, it is found that it involves hardly a measurable retardation of the reaction by the time the 50 per cent point is reached.

A logarithmic relation between time and the concentration of a reacting substance is quite general in chemical reactions not involving migration. Two such arcs of differing constants are not so easily explained.

Hathaway has shown in the Appendix that the carbon con-

centration of a spherical mass originally of uniform concentration from which the carbon is removed by precipitation at the center is

$$6k_0 \sum_{n=0}^{n=\infty} \frac{e^{-h^2t(2n+1)^2\frac{\pi^2}{4}}}{(2n+1)^4\frac{\pi^4}{16}} \qquad (5)$$

where k_0 is the original concentration, e is the base of the Naperian system of logarithms, h^2 is the diffusivity of carbon in iron, and n the number of the term in the series, and t the time.

It has been further shown there, that while the locus of this expression cannot even be approximated in any reasonably small number of terms, the curve is similar to a logarithmic one except that it is more steeply convex toward the axes of reference. It may be that the two logarithmic curves are merely an empiric approximation at Hathaway's equation.

The beginning of the first logarithmic curve at 76 per cent completion of the reaction corresponds very nearly with the composition calculated for the cementite free zones by equation (4). However, we find that the value of k_0 in the equation of the last portion of the curve is 22 per cent, which also corresponds rather closely to this carbon content.

We are here confronted with two possible explanations between which it is, as yet, impossible to decide upon strictly experimental evidence. We may assume that the intersection of the final logarithmic curve with $t = 0$ represents the 23 per cent of ungraphitized carbon existing at the moment when all cementite is destroyed. If so, we must believe that the graphitization of solid solution is not influenced by migration rate, but either that carbon graphitizes, in situ, or else so slowly that it can always find time to migrate to a nodule in the neighborhood.

On the other hand, we may assume that the two logarithmic arcs represent an approximation at the locus of Hathaway's equation, and that we are really concerned with a reaction, whose velocity is determined by rate of migration, which begins at the point in time where cementite is all destroyed, and corresponding in theory to an ungraphitized carbon content of 23 per cent, as compared with the 24 per cent observed as the beginning of the earlier logarithmic arc.

Graphitization, in situ, is improbable, for there is no microscopic evidence of the existence under these circumstances of very finely divided graphite. Hayes(8) demonstrated such a structure

to characterize the stable eutectoid, which cannot here have been formed. As the differences in carbon concentration diminish, and the migratory distances increase, the rate of migration of carbon should decrease. If the original reaction velocity was determined by rate of migration, then it is difficult to suggest why that, at a later stage, should not also be so determined when the migratory rate has decreased. If we assume that the two logarithmic arcs represent substantially the locus of the Hathaway equation (5), then the coincidence that the apparently logarithmic final curve intersects the $t = 0$ line at a point in ungraphitized carbon near that corresponding to the disappearance of cementite arises from the symmetry of all the graphitization curves, and the extrapolated curve has no metallurgical significance. This view is believed to be the more logical. Another interpretation is suggested following conclusion IV.

The curve shown in Fig. 3 differs from those previously discussed in that it is apparently composed of only two arcs. The first is of the form of equation (2), the latter of equation (3). Fig. 5, however, shows that here we are not encountering the entire removal of cementite from zones around the carbon nodules, but mainly that of eutectoid cementite. The point of inflection of the curve, marking the change from one mathematical form to another, corresponds to the disappearance of pearlite and of such portions of proeutectoid and eutectic cementite as are destroyed at the same time.

It is noteworthy, also, that we have here evidences of major migrations of carbon at a temperature below A_1, where carbon is nearly insoluble in either system. We do not encounter Hayes' eutectoid(8), but large nodules of carbon. This observation does not contradict that of Hayes, who observed the formation of the stable eutectoid on cooling slowly to, and through Ar_1 stable, and did not report on long continued treatments entirely below A_1.

The paraboloid in this curve represents a migration rate through the ferrite. The significance of the logarithmic curve in the destruction of cementite has not yet been studied sufficiently to permit definite conclusions. It may represent an interface reaction at the surface of contact of cementite and ferrite, or in some other way represent a reaction decreasing as the amount of cementite decreases. We have thus shown that:

III. Graphitizing rate is determined by the rate of migration

of carbon, in some form, through solid solution, or through ferrite.

Further, we have examined the possibility that graphitization is an interface reaction occurring at the surface of contact of carbon and solid solution, for example. It is shown in the Appendix that if this be true, then the relation

$$c = at^3 \qquad (6)$$

should exist throughout. Since carbon is shown not to be a cubic function of time, but that actually

$$c = at^{1.5} \qquad (2)$$

or $c^2 = at^3$

is proof that we are not concerned with an interface reaction.

Leaving further conclusion for a later part of this paper, we may now use our newly gained knowledge for a practical application which in turn will permit a further theoretical development.

Measurement of Graphitizing Rate

Reference has already been made to the fact that various experimenters(1)(2) have concerned themselves with the time required to attain equilibrium. Our previous considerations will show that this time is infinite in all cases, since the logarithmic terminal curve becomes horizontal only at infinity. What is actually measured in such cases is only the time until the observer can detect no further changes in what seem to him sufficient time. The time decided on, therefore, increases with every increase in experimental precision.

Now, a more accurate and infinitely more rapid means for measuring graphitizing rate is rendered available by the previous portion of this research. We have shown that all graphitization curves begin with a curve of the form of equation (3):

$$c = at^{1.5}$$

where c is the percentage of graphite existing at time, t, measured in any desired units, usually hours, and a is a constant.

We may very readily determine the rate of graphitization

mathematically by differentiating this equation with respect to c and t, whence we get

$$\frac{dc}{dt} = 1.5\ at^{0.5}$$

$$\text{but} \qquad t^{0.5} = \left(\frac{c}{a}\right)^{1/3}$$

Hence, substituting and reducing to the simplest form,

$$\frac{dc}{dt} = 1.5\ a^{2/3}\ c^{1/3} \qquad (7)$$

which means that the rate of change of carbon is proportional to the cube root of the carbon content, and to the cube root of the square of the experimental constant a.

If the data are desired in terms of per cent of completion of graphitization, as plotted in Fig. 2, it is merely necessary to calculate over from per cent graphite to the ratio which that percentage bears to the possible graphite; i. e., the total carbon minus the solubility of carbon in the stable system under the conditions chosen.

Now, since the rate of formation varies continuously as the graphite content c varies, we can compare two metals, or two temperatures, only at a given graphite content. Our mathematical considerations have shown, however, that the ratio will be the same whatever carbon content be chosen. We thus have the conclusion that graphitizing rate is proportional to $a^{2/3}$ where a is an experimental constant which may be easily and quickly determined by heating a specimen of the material a given time at the temperature under consideration, and determining the percentage of graphite. By substituting for c and t, their determined values a, can be calculated. It is only necessary that the graphite precipitated be less than one-half that available. This condition is met by the selection of a suitable time. A different value of a will be found for each temperature. This subject will be developed somewhat more fully on a later page.

The necessary considerations to take care of differences in total carbon have been previously discussed. With that minor exception, the time required to approach equilibrium within any given percentage is inversely proportional to $a^{2/3}$. The development of this method of measuring graphitizing rate is deemed the

most important commercial result of the present research, for by its means we can compare with quantitative precision any number of hard irons with respect to the ease or difficulty with which they can be annealed. In this way future experimenters can record the quality of material used in researches on graphitization. As a consequence we will be able to compare data from various sources, and determine to what extent they are based on similar material.

When conclusions are drawn as to the time required for the completion of the graphitizing reaction, we will be able to determine to what extent the results are influenced by possible peculiarities of the material studied. It is not impossible to find graphitizing rates in commercial metal differing in the ratio of six to one.

Another method of measuring graphitizing rate can be used when necessary, although that just described is preferable. Instead of working on the first, or paraboloid, segment of the curve, we may work on the last logarithmic arc, when less than 15 per cent of the carbon remains to be deposited. We have then, that graphitizing rate is measured by the first derivative of equation (3), whence

$$d \log k = -b\, dt$$

$$\text{or} \quad \frac{dk}{k} = -b\, dt$$

$$\text{or} \quad \frac{dk}{dt} = -bk \qquad (8)$$

whence the graphitizing rate is *proportional to* b. It is not equal to b, for we have neglected certain numerical constants. From conclusion (I) it follows that any variation in conditions affects $a^{2/3}$ and b in the same proportion. We can then as easily compare graphitizability by comparing values of b as of $a^{2/3}$. There are only occasional instances when this is advantageous, however. The two constants $a^{2/3}$ and b are not numerically equal, although both fundamentally derived from the same constant; i. e., one measuring migratory rate or diffusivity. If we had introduced into our mathematics a value for carbon concentration gradient, depending upon the mean length of the path of migration, and upon the value of $k_{em} - k_{gr}$ as used in equation (4), both could have been expressed in terms of the constant h^2 in equation (5) and a definite quantitative relation established.

Since the curve is smooth, it follows that the migratory rate

does not alter discontinuously, for example, at the point where cementite disappears, whence we may conclude that:

IV. In any given system either the form in which the carbon migrates is always the same, or carbon in all its forms migrates in iron at the same rate, or the form in which the carbon migrates changes continuously with a corresponding continuous change in graphitizing rate.

Beginning with this assumption, we may, perhaps, consider a minor modification of the interpretation of the graphitization curve.

The derivation of the mean carbon content of the cementite-free spheres surrounding nodules of carbon postulates a constant migratory rate for carbon. Now, if the rate of migration of carbon in the stable solid solution (boydenite[6]) be greater than in the metastable solution (austenite) and there be also a transition in *character* of solid solution as we pass from that in contact with cementite to that in contact with carbon, then the curve relating to carbon concentration as ordinate, to distance from the carbon as abscissa will be steeper near the end next the cementite and flatter at the end near the carbon than as calculated, and, hence, the mean carbon concentration will be lower.

Assume that it approximates somewhat over 15 per cent of the graphitizable carbon. Then the theoretical termination of the paraboloid arc extends beyond the calculated 43 per cent toward the 52 per cent of graphitized carbon calculated, say to 48 per cent or so. We then interpret only the last logarithmic arc as an empiric approach to Hathaway's equation, the first logarithmic arc becoming an empiric approximation at the effect of completion of the destruction of cementite. We are unable experimentally to decide between these several assumptions, although the author inclines to the latter belief as the most probable.

The author has been unable to subscribe to the postulate upon which Jeffries and Archer (14) founded their conclusion, that the migration of carbon in austenite demonstrated the fact that it could not be present as cementite. It may, however, be considered at least probable that if boydenite and austenite differ in atomic arrangement, then carbon will migrate more rapidly in the former.

Had a definite difference in migration rate been proven to exist instead of merely shown not to be impossible, an important

step would be taken in deciding the question of why carbon has two solubilities in gamma iron at a given temperature, and why the alpha-gamma transformation takes place at widely different temperatures in the two systems(7). Such a difference in migratory rate between phosphorus as atoms and as iron phosphide has been reported by Fry in *Stahl und Eisen*, Vol. 43, Aug. 9, 1923, p. 1039.

Effect of Temperature on Graphitizing Rate

Having at command a method of measuring graphitizing rate, it becomes an obvious step to attempt the solution of the relation between this function and temperature. The value of $a^{\frac{1}{6}}$ as used in equation (7) was accordingly determined on several metals at each of four different temperatures, all above A_1.

It is a general rule of physical chemistry that equal increments of temperature multiply the velocity of a reaction by equal amounts. Very generally, an increase of 10 degrees Cent. approximately doubles the reaction velocity(9). Ishiwara has shown(10) that the rate of diffusion of carbon in (gamma) iron is multiplied by 1.103 for a rise of 10 degrees Cent. In either case there is evidence that the same principle should apply to our reaction, whether we view it from the view point of the effect of temperature on diffusivity, or reaction velocity.

A graph made by plotting the change in reaction velocity by an increment of 40 degrees Cent. in temperature against the mean velocity was nearly a straight line. In fact, the results agreed with this law much better than with any other quantitative relation which could be formulated. The effect of an increment of 10 degrees Cent. is not quite constant, however, depending upon the chemical composition, especially the silicon content, but is of the order of magnitude of multiplying the initial rate by 1.23.

We conclude that:

V. Equal increments in temperature multiply graphitizing rates by equal amounts.

The fact that the thermal coefficient of the graphitizing reactions resembles somewhat the Ishiwara coefficient is to that extent corroboration of the fact that graphitization rates are determined by migration rates. The difference in the coefficients may point to a difference in mechanism of migration in the stable and metastable systems resulting in greater mobility in the former.

It has been concluded by Gladhill (11) on the basis of calculation by C. H. Berry, that, if H be the time to attain equilibrium at temperature T, and m and b are constants, then

$$T = m \log H + b$$

From Gladhill's graphs and context, and since the above equation requires an increase in annealing time as the temperature rises, it is thought that this is an error, and that it was intended to say that

$$T = b - m \log H$$

some slip having occurred in translation from English to French and back again. Admitting the validity of this correction, and of our conclusion (I), Gladhill's data show that the logarithm of the graphitizing rate is proportional to the temperature which is a mathematical wording of our conclusion (V). This agreement in conclusions between Gladhill's measurements and conclusions, and the results of experiments based on our theory is believed to constitute strong proof of the accuracy of both investigations and of our reasoning.

A little work has been done to determine the temperature coefficient of the graphitizing reaction at temperatures below A_1. The limitations of experiments in this region are the slowness of the reaction and the comparative unimportance of the field industrially. It was, however, shown that the temperature coefficient of the reaction between 1360 and 1290 degrees Fahr. (740 and 700 degrees Cent.) was apparently negligible. Certain rather interesting studies are made possible by our knowledge of the effect of temperature on graphitizing rate.

Reaction Velocity Above and Below A_1

From conclusion IV we may extrapolate downward from data obtained at higher temperatures, and obtain the reaction velocity in gamma iron solutions at A_1. From data obtained below A_1 we may extrapolate upward and determine the reaction velocity in alpha iron solutions at A_1. As indicated just previously, we may actually apply without correction practically any result obtained above 1290 degrees Fahr. (700 degrees Cent.). In a specific case, the value of a in formula (2) at A_1, 1290 degrees Fahr. (760 degrees Cent.), by extrapolation from data at 900 degrees Cent. and

780 degrees Cent. is 0.0001085, as against a value observed at 740 degrees Cent. of 0.00006749. Having in mind the uncertainties of the derivation, we can only say that the reaction velocity is of the same order of magnitude on both sides of A_1. Inasmuch as we have no knowledge of the gradient in solubility of C between alpha iron saturated in the presence of cementite and of graphite, we lack an essential step in a strictly mathematical analysis of the theory.

Effect of Silicon on Reaction Rate

It is well known that silicon increases the annealing rate. Gladhill for example(11) gives data which are a qualitative proof of this fact. It is not the writer's intention to suggest in what follows, that silicon alone determines reaction velocity. This is far from the truth. The discussion of the effect of silicon is applicable only to the conditions in which all other independent variables are rendered inoperative. Under such conditions, i. e., on metal varying chemically only in silicon content, made under the same conditions, from similar melting stock, poured into specimens of constant size, all of which froze at the same rate, the following conclusions were reached:

On a series of such specimens, ranging from 0.5 to 1.5 per cent in silicon, $a^{2/3}$ was computed from graphitization experiments carried on at 900 degrees Cent. and at 780 degrees Cent. The results agreed, within the limits of error of the experiment, with a curve of the form

$$\log a^{2/3} = a' + b' \, Si,$$

where a' and b' are constants, and Si is the silicon concentration. We conclude, therefore, that:—

VI. Equal increments of silicon multiply the graphitizing rates by equal amounts.

The writer has elsewhere (7) expressed the view that the solubility of carbon in the stable and metastable system may be identical in the pure iron-carbon alloys. If this be the case, graphitization may not proceed at all in the absence of silicon. This conclusion is not in agreement with the preceding conclusion (VI), for a finite reaction velocity at silicon equal to 0.50 per cent cannot be reduced to zero for a reduction of silicon to zero, so long as a finite increment of silicon multiplies reaction velocity by a finite amount. An infinite factor would produce an infinitely rapid reaction with any finite amount of silicon.

It is quite possible that a still more careful study would reconcile the discrepancy. The difference in solubility of carbon in the stable and metastable systems has been shown (loc. cit.) to increase with the silicon content up to about 4 per cent silicon. This involves an increase of steepness in carbon gradient with increasing silicon, and, hence, at constant diffusivity would produce a linear increase in migratory rate with silicon at any constant temperature. If the presence of silicon also, per se, multiplies the diffusivity, then the resultant of the two effects would be a curve in which at low silicon concentration, migratory rate would approach a linear function of silicon and at high concentration an exponential function of that element. Such a curve plotted as log $a^{2/3}$ against silicon would pass through the origin, be convex toward the log $a^{2/3}$ axis, and finally approach an inclined straight line resembling that obtained from the first assumption except that it would not pass through the origin if prolonged. That silicon promotes carbon migration is contradicted by the data of Tammann (13). It is quite possible that VI is a first approximation of the facts which neglects the regions low in silicon.

It cannot, as yet, be said whether conclusion (VI) requires modification for low silicon contents, or whether the former suggestion is invalid.

A long continued experiment is in progress to determine whether an alloy low in silicon (about 0.02 per cent) can be caused to graphitize at a temperature of 1650 degrees Fahr. (900 degrees Cent.) maintained for many months. Only thus will the point to be cleared up.*

Effect of Silicon on the Thermal Coefficient of the Graphitizing Reaction

As an incident of many experiments made to determine graphitizing rate, it has been observed that a given increment of temperature affects the graphitizing rate of low silicon iron more than that of high silicon iron. This is certainly true qualitatively; whether the relation is also true quantitatively is not

*Note:—Since the preceeding was written the results of this experiment show that such graphitization does not occur measurably in 2075 hours.—The considerations advanced by the present author in discussing Dr. Hayes' (15) paper on "The Carbon Content of Pearlite in Iron-Carbon Alloys Containing One Per Cent Silicon" indicate that there should be a discontinuity in the quantitative effect of silicon at that concentration near 2 per cent, where A_3 passes below A_1.

so certain, for it is somewhat doubtful to what extent unsuspected variables may enter in a collection of such data as form the basis for our conclusion. Most of our data would agree fairly well with the ratio, a relation such that the logarithm of the reaction velocities at 900 and 780 degrees Cent. decreased as a linear function of the silicon content. We conclude that:

VII. The presence of silicon decreases the thermal coefficient of the reaction velocity in an, as yet undetermined, degree; the relation may approximate that the logarithm of the thermal coefficient is a linear function of the silicon concentration. This quantitative relation follows mathematically from V and VI, and any departure therefrom would require a further study of the cause of such variations to determine whether a modification of VI is requisite.

The subject is mentioned here mainly for comparison with the conclusions of Dhar(12) that the presence of a positive catalyst decreases the thermal coefficient of the reaction velocity. So far, the writer is not aware of any publication which explains the mechanism of the effect of silicon in promoting graphitization. The mere statement that silicon decreases the solubility of carbon is begging the question, for it merely asserts a truth, but does not explain it. It is not the intention here to defend the thesis that silicon acts merely catalytically, but merely to point out a relation not inconsistent with that belief. Personally, the writer believes a more definite explanation possible, and even probable.

Future Developments

A survey of all the known elements from a literary or experimental view point has recently been completed in this laboratory to determine which elements help and which hinder the graphitizing reaction. There are both scientific and commercial reasons for not enlarging upon the results of that research in the present connection. We have, however, a legitimate hope that these data, when studied in the light of the knowledge the present research has given regarding the theory of graphitization, will permit of further verification of our present conclusions, and will also shed further light on the fundamental mechanism of the graphitizing reaction.

Conclusions

The researches herein discussed have led to seven major

conclusions which have already been given in their proper places. They may well be repeated here.

I. All graphitization curves are alike when plotted to ordinates representing graphite formation as a percentage of the possible total and time, using as a unit that required for the completion of half (or any other constant fraction) of the total reaction.

II. Graphitization proceeds by an increase in size rather than of number of carbon nodules.

III. Graphitizing rate is determined by the rate of migration of carbon, in some form, through solid solution or through ferrite.

IV. Either the form in which the carbon migrates is always the same, or carbon in all its forms migrates in iron at the same rate.

V. Equal increments in temperature multiply graphitizing rates by equal amounts.

VI. Equal increments of silicon multiply the graphitizing rates by equal amounts.

VII. The presence of silicon decreases the thermal coefficient of the reaction velocity in an, as yet, undetermined degree; the relation may approximate that the logarithms of the thermal coefficient is a linear function of the silicon concentration.

From these facts we construct an image of what occurs in the process of graphitization, particularly above A_1, although the reader will be able to make suitable inferences as to the process below A_1.

The hard iron on heating to the graphitizing temperature becomes a heterogeneous aggregate of austenite and cementite. There then appear by an unknown mechanism in the austenite nuclei for the crystallization of carbon. The solid solution adjacent to these nuclei deposits carbon and becomes boydenite(6). It is thus lower in carbon than austenite, and carbon migrates toward it from the austenitic areas which recoup their carbon content by dissolving cementite.

Inasmuch as all the austenite interspersed with cementite is thereby maintained saturated as to carbon, no gradients exist for any carbon migration in these regions. In the region, however, adjacent to nuclei, cementite has been destroyed, and there exists a mass of solid solution, boydenitic at the center, austenitic at the surface through which carbon migrates, toward the center

and is deposited on to the nucleus as rapidly as it arrives. The cementite-free zone thus grows rather uniformly until that constituent is all destroyed, and the carbon it contained is deposited as nodules. Thereafter the solid solution is of unequal carbon concentration, and further carbon flows inward until the boydenite concentration is established throughout. The reaction then ceases.

It is obvious that the rate of deposition of carbon from boydenite is necessarily greater than the rate at which carbon migrates under the experimental conditions. It is quite obvious that the rate at which carbon can migrate toward the nodules depends on their distance apart and the diffusivity (conductivity) of carbon in iron. We might, indeed, calculate from known values of graphitizing rate and grain counts, an approximate numerical value.

Tammann has shown(13) that the diffusivity of carbon in iron is a rather complex process, apparently related to grain boundary conditions in a poorly understood manner. Even the apparently simple corollary that graphitizing rate should be primarily an expression of number of nuclei does not seem to be acceptable without considerable qualifications.

As a practical conclusion, the discovery of a simple and relatively easy means of measuring graphitizability by calculation from the carbon precipitated in a given, relatively short time, is, perhaps, the most important feature of this paper.

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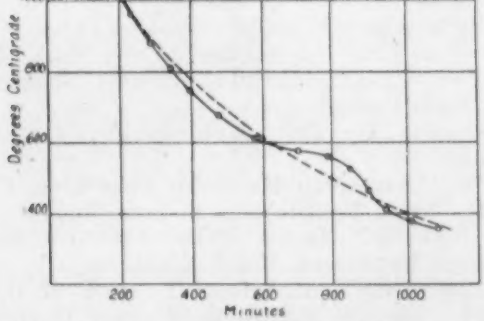
The Appendix containing the mathematical derivations by Hathaway referred to in the text, together with the discussion of the paper which took place following its presentation, will be published in the July, 1926 issue of TRANSACTIONS.

DISCUSSION—SOME CHARACTERISTICS OF QUENCHING CURVES

(Continued from Page 882)

body of the report throws interesting light upon Mr. Archer's comments regarding air cooling.

It will be observed that the curve derived from data on relatively small sections shows exceedingly good agreement with the actual center cooling



curve of this large ingot thus confirming the authors' views regarding the better prospect of duplication of results when cooling in air than in certain liquids such as oils and water.

IRREGULAR CARBURIZATION OF IRON AND IRON ALLOYS — THE CAUSE AND PREVENTION

By W. J. Merten

Abstract

The experiments on carburizing of steels, conducted by the author and a careful study made of the carburizing process in its various details, points decidedly toward a general omission, by practical metallurgists, of fundamentals, including the conditions of the materials, processes, and equipment for satisfactory results.

It is the purpose of this paper to point out these conditions, setting forth the physico-chemical reactions within the carburizing container. It shows that the chemistry of the steel plays only a minor role in the success of the satisfactory production of a proper depth and uniformity of case, and that the physical structure of the steel and the mechanical arrangement of steel articles and carburizers for correct chemical reactions are the major factors.

Introduction

STRUCTURAL irregularities of steel,—their influence upon and behavior toward carburization,—have been given considerable attention and space in the metallurgical literature. Much theorizing has been done until there has been compiled such a maze of circumstantial evidence for the conviction of the steel as the guilty party that anything short of positive proof to the contrary will not have a chance of a hearing.

An investigation of the carburizing process in its various details, as a possible offender, seems to have been entirely overlooked, or perhaps the process has not been fully understood by the investigators. The possible real progress along these lines has evidently not been realized by these investigators. It is the writer's purpose to bring out the facts as they have occurred in his experience to show that at least some of the so-called unsatisfactory steels have carburized perfectly upon being subjected to the cementation process, and to point out that much of the condemnation of the steel in question is due to the carburizing process rather than the steel involved.

A paper presented before the Cleveland Convention of the Society, September, 1925. The author, W. J. Merten, member A. S. S. T., is metallurgical engineer with the Westinghouse Electric and Manufacturing Co., East Pittsburgh.

The Bureau of Standards in its 1924 Progress Report on "The Investigation of the Character of the Steel Used on the Results Obtained in Carburizing" reported that their investigation establishes proof for abnormality of steel, as shown by its reaction toward carburization. In our practice at the Westinghouse Electric and Manufacturing Company, by careful structural refinement through thermal treatments and selective heating and quenching methods, confirmation of this is entirely lacking.

The Carburizing Process

Before going into the subject of the cause of irregularities, it will be of value to review the details of the carburizing process as it is conducted today.

Carburizing Materials—Their Characteristics and Their Chemical Activity

All carburizers, whether solid, liquid, or gaseous, contain carbon as a base. The usual carbon base for solid carburizers is charcoal, petroleum coke, charred leather, etc. These are compounded with alkaline carbonates, or cyanides, the so-called energizers.

Sodium, barium, and calcium carbonates are the commonly employed energizers. Pure sodium and barium carbonates, plus charcoal, require, however, a high temperature for calcining or freeing of CO_2 from the carbonate.[1] $BaCO_3$ at 2010 degrees Fahr. (1100 degrees Cent.) yields $BaO + CO_2$, $CaCO_3$ at 1290 degrees Fahr. (700 degrees Cent.) yields $CaO + CO_2$ and Na_2CO_3 at 1830 degrees Fahr. (1000 degrees Cent.) yields $Na_2O + CO_2$. Calcium carbonate ($CaCO_3$) has the lowest heat of dissociation of the three mentioned.

Magnesium carbonate ($MgCO_3$), although not used as commonly, has considerable advantage and even at as low a temperature as 100 degrees Cent. will start to decompose and cannot, therefore be entirely dehydrated. Its quantity of heat of dissociation is 60,863 calories at 1006 degrees Fahr. (540.8 degrees Cent.) and 747 millimeters pressure yields all of its CO_2, or decomposes entirely. Its chief advantage lies in the readiness with

[1] Landolt and Bornstein.

which it is dissociated, partial dissociation starting at low temperatures. Sodium and barium carbonates are more stable and when heated singly do not give up their CO_2 until a temperature of 1800 degrees Fahr. (1000 degrees Cent.) or more is reached, which temperature is practically out of the range of temperature where carburizing is conducted. A lowering of the heat of dissociation of sodium and barium carbonates, so as to give up their CO_2 at carburizing heat is affected by mixing them with calcium or magnesium carbonates. Even the mixing of the two stable salts seems to bring a lowering of the calcining heat. The reactions necessary for cementation are the freeing of CO_2, or production of CO_2 from the energizers, and the inter-action of CO_2 with incandescent carbon forming CO as shown in the equation

$$CO_2 + C = 2CO.$$

This CO formed interacts with iron to form iron carbide and CO_2 as follows:

$$2\,CO + 3\,Fe = Fe_3C + CO_2.$$

To form carbon monoxide (CO) from carbon dioxide (CO_2) incandescent carbon at a temperature not less than 1470 degrees Fahr. (800 degrees Cent.) is necessary. Carbon dioxide (CO_2) produced at a low temperature from $MgCO_3$ can and does produce unfavorable atmospheric conditions within the container and in presence of moisture may become intensely oxidizing or corrosive in action, thereby retarding the carburizing process, since the reduction of the oxide must necessarily precede the cementation reaction. Due to this fact $MgCO_3$ ordinarily is not used alone but is used mixed with a more refractory carbonate, such as barium carbonate ($BaCO_3$). If, however, CO_2 as produced from $MgCO_3$ at a low temperature is passed through a bed of charcoal, at red heat of approximately 900 degrees Cent. to form CO, and the CO formed is brought into contact with iron held at the carburizing heat, satisfactory and high grade carburizing can be accomplished. The dissociation heat of calcium carbonate is also too low and its use singly is unsuitable for similar reasons.

The ideal energizer is a carbonate or a mixture of carbonates which:

1. Does not give up its CO_2 until the iron has attained the

carburizing temperature, or is in the gamma iron or face-centered crystalline state.

2. The residual product of the carbonate must not react with CO to form the carbide at the temperature of the process. Iron carbonate ($FeCO_3$) which dissociates at a low temperature (below red heat) is for this reason unsatisfactory. The reduced chemically pure iron reacts more readily with CO in forming Fe_3C than the steel article in the container. The following reaction illustrates the chemistry of the interaction of iron carbonate and carbon at incandescence:

$$FeCO_3 = FeO + CO_2 \text{ and } CO_2 + C = 2CO$$
$$FeO + CO = Fe + CO_2$$
$$3Fe + 2CO = Fe_3C + CO_2$$

3. The metal oxide residue of the energizer must be stable at the temperature of carburizing, or be highly refractory and chemically inert in the system under consideration. It may, however, reform the carbonate and make the process regenerative. It is for this reason, in addition to those stated above, that the alkali-earth carbonates are the most satisfactory energizers.

The presence of hydrogen or hydrocarbons as binders, or water of crystallization, have a decided accelerating effect upon the carburizing process, and when present are the main factors to produce a hyper-eutectoid case. CH_4 is the most noteworthy of the hydrocarbons in this respect, and apparently a sufficient quantity of this gas is evolved around 1100 degrees Fahr. to produce a carburizing atmosphere and a carburizing reaction, providing the iron is chemically active to form Fe_3C. This, however, is not particularly in keeping with our most recent investigation of the properties of alpha iron; alpha iron does not hold carbon or iron carbide (Fe_3C) in solid solution, and chemical reaction between alpha iron and CO at temperatures below 1400 degrees Fahr. (760 degrees Cent.) is also rather questionable in an atmosphere existent in a carburizing box.

The chemical reactions[2] involved are:

$$Fe_3O_4 + CO = 3\ FeO + CO_2 \quad (1)$$
$$3\ FeO + 5\ CO = Fe_3C + 4\ CO_2 \quad (2)$$
$$CH_4 + 3\ Fe = Fe_3C + 2H_2 \quad (3)$$

[2]See Physical Chemistry of Metals, by Rudolph Schenk. Translated by R. S. Dean.

Fig. 1—Carbide Concentration on the Surface of a Low Carbon Steel Die Insert After the Carburizing Treatment. The Steel was in a Highly Strained Condition Resulting from the Cold Pressing Operation. This Roughened Condition May Be Entirely Avoided by Normalizing the Steel Before and After Cold Pressing. Enlarged 5 times.

Preparation of the Iron or Steel Parts and Packing and Distribution in the Containers—Causes of Irregularities

Steel generally used for carburizing is a low carbon open hearth steel from 0.15-0.25 per cent carbon, although electric furnace and Bessemer converter steel are at times used. Articles or parts for carburizing are generally made of hot-rolled steel, drop forgings, or hot-pressed parts. In special and infrequent cases, cast

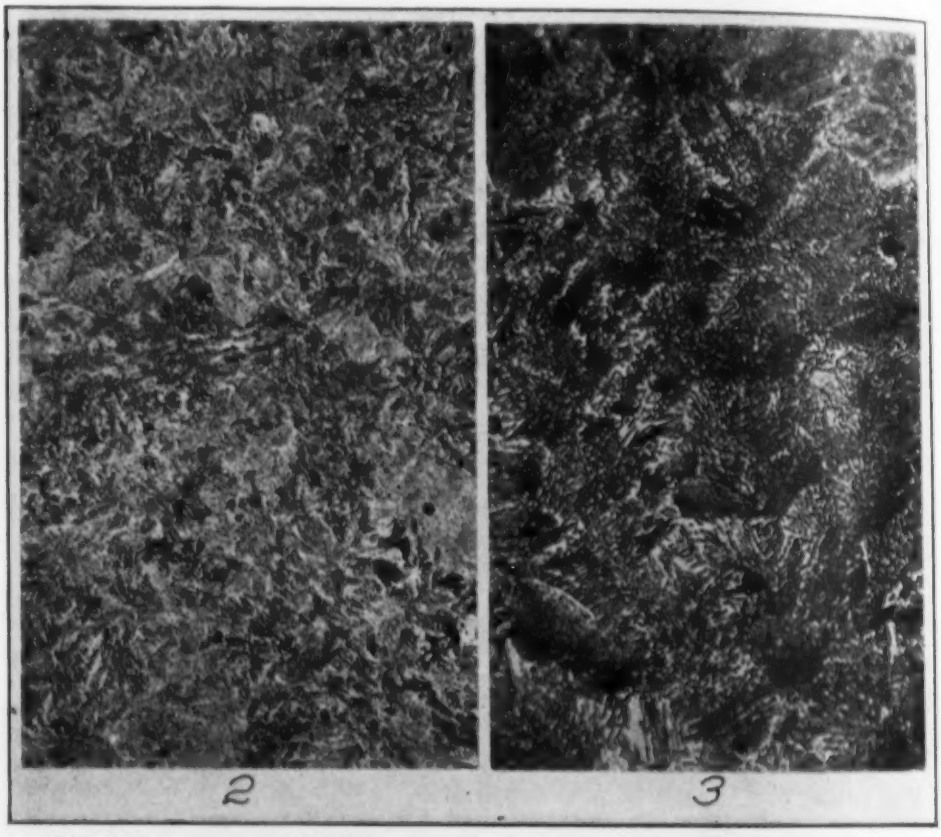


Fig. 2—Photomicrograph of Die Insert of Fig. 1 Showing Carbide Concentration. 100 X.
Fig. 3—Same as Fig. 2. Showing Another Section of the Die Insert. 100 X.

steel parts are carburized. It is common practice to machine and then carburize the parts without even giving them an anneal after the hot working. A hot bed anneal or slow cooling from the finishing heat is often considered sufficient preparation for the subsequent cementation process. This is far from being the correct practice, as an experiment will show. A die insert made of soft steel and sunk by hydraulically impressing the design and contour, when carburized in the cold-pressed and highly strained

condition gave a rough and coarsely grained surface concentration of carbide, as is shown in Fig. 1. This is probably due to an intense grain growth of the strained material and the breaking down or refinement of the large grains at the carburizing heat, when the chemical reaction between iron and carbon monoxide resulted in a coagulation of iron carbide particles, which ordinarily can only take place at lower temperatures. Repeated tests of carburizing directly after cold pressing invariably gave the knurled surface appearance, visible to the naked eye. That excessive grain growth is very likely the explanation of the phenomenon was shown by carburizing test pieces of approximately the same dimensions as the die inserts which had been subjected to prolonged heating at 2100 degrees Fahr. and were very slowly cooled and had consequently a coarse grain structure. The surfaces after carburizing were rough and similar to those encountered on die inserts. Very long time heating in the carburizer obviously will alter these conditions. A very slow carburizer may also give different results. This concentration of carbide and roughening of the surface is entirely avoided and a deep, uniform case produced by normalizing the steel before cold pressing, again normalizing after cold pressing and before carburizing, proving that the structural conditions are an important factor in the production of a smooth and uniform cementation of finished machined parts. This is of particular importance in carburizing gears and pinions to avoid a surface roughening of the teeth, which results in flaking and spalling. Pitting of surfaces is due to this phenomenon and is generally attributed to other causes. Photomicrographs of the die insert of Fig. 1 are shown in Figs. 2 and 3.

Neither is it considered necessary by some practical heat treaters to have the steel parts entirely free from scale (Fe_3O_4) and especially on drop forged parts, scaled parts or areas are sometimes considered an advantage, since it offers protection against carburizing of these areas. However considering the chemical reactions of scale and carbon as given in the following equations,[3]

$$Fe_3O_4 + CO = 3\,FeO + CO_2$$
$$CO_2 + C = 2\,CO$$
$$FeO + CO = Fe\ (powder) + CO_2$$
$$3Fe\ (powder) + 2\,CO = Fe_3C\ (powder) + CO_2$$

the speed of reaction on the steel is reduced and the efficiency of

[3] R. Schenk.

the carburizing process is lowered both as to time and character of case, and causes the disturbances in the cementation reaction. It becomes evident that oxide scale Fe_3O_4 is of a deleterious character in a carburizing container and should be removed before the steel is subjected to this process. This same reasoning must be applied to protective layers and coatings of cement for selective cementation, most of them being of an oxide character, which introduce disturbing elements into the carburizing container. They are

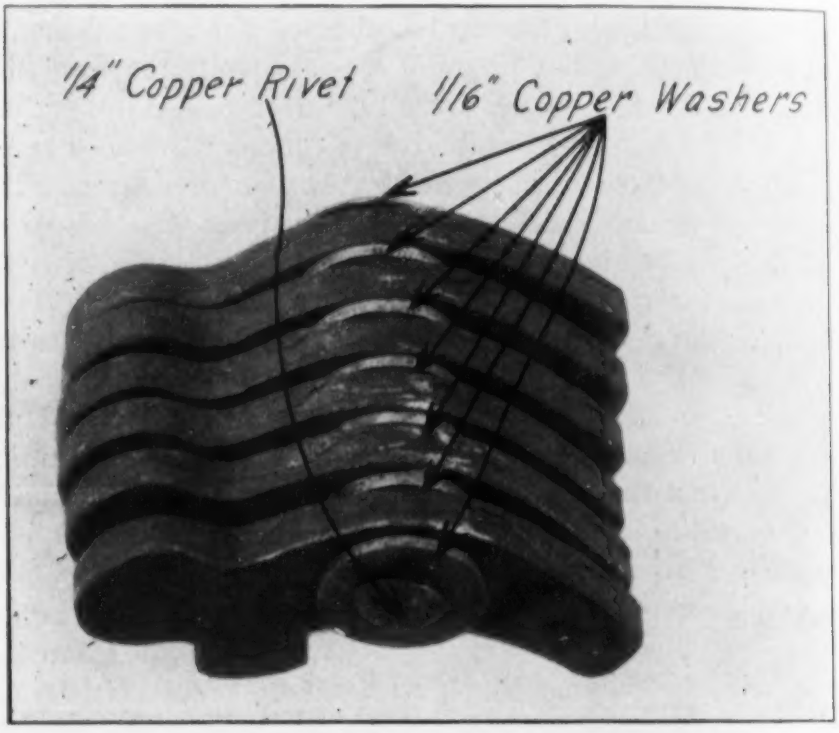


Fig. 4—An Example of Selective Carburization of Steel Triggers. The Washers and Rivet are Copper.

chemically active at carburizing temperatures where inert conditions of such protective coatings are essential. Even copper plated parts are not free from this objection on account of oxide inclusions and contamination of the electro-deposit. Pure solid copper bodies placed against or around parts to be left soft serves a better positive means for such practice. Fig. 4.

Carburizing after casting without heat treatment to break up the cast structure or the so-called structure of primary crystallization, or dendritic structure, is objectionable from above mentioned reasoning and, consequently, any test for carburizing on

chilled cast bars or any cast test bar ingot cannot be a criterion of the quality of that steel for cementation or carburizing.[4]

Packing of the parts into the container ordinarily involves covering the bottom with carburizing compound to a thickness of probably 1 inch, with spacings of approximately 1 inch between the individual pieces, and filling carburizing compound between them. Naturally, gas evolution and chemical reaction between gas

Fig. 5—Die Inserts Showing Spotted Surfaces Caused by Irregular Carburization.

and steel is not especially favored by surface contact of carbon with steel. It is evident that the areas in contact with the energized particles of the carburizing material are also adjacent to a vigorous chemical reaction occasioned by the dissociation of the CO_2 furnishing ingredient and may influence the cementation reaction locally. It is even possible that temporarily oxidizing conditions prevail at such areas of contact with consequent formation of superficial iron oxide subsequently broken up. Disturbances of this character naturally result in variations in depth of carburization in comparatively short time processes.

Still more unfavorable conditions become prevalent when the carburizing material becomes pulverized and actually shrouds the steel from contact with the gases. Consequently unsatisfactory progress of carburizing ensues. A still greater menace is the fusible ash residue, consisting of a fusion of the small amount of

[4]McQuaid-Ehn test. TRANSACTIONS of the American Society for Steel Treating, 1922, Vol. 2, page 1177.

silicious ash and alkali carbonates in the carburizers, forming a silicate slag, which is the cause of pitting and surface scoring of the steel, resulting in decarburization and inter-granular attack of the steel in the surface layers. Fig. 5. After packing and filling the container, as described above, to within ½ inch from the top, a fairly tight fitting cover is put on and the joints sealed or luted with fireclay. Fig. 6 shows a self-sealing box and cover

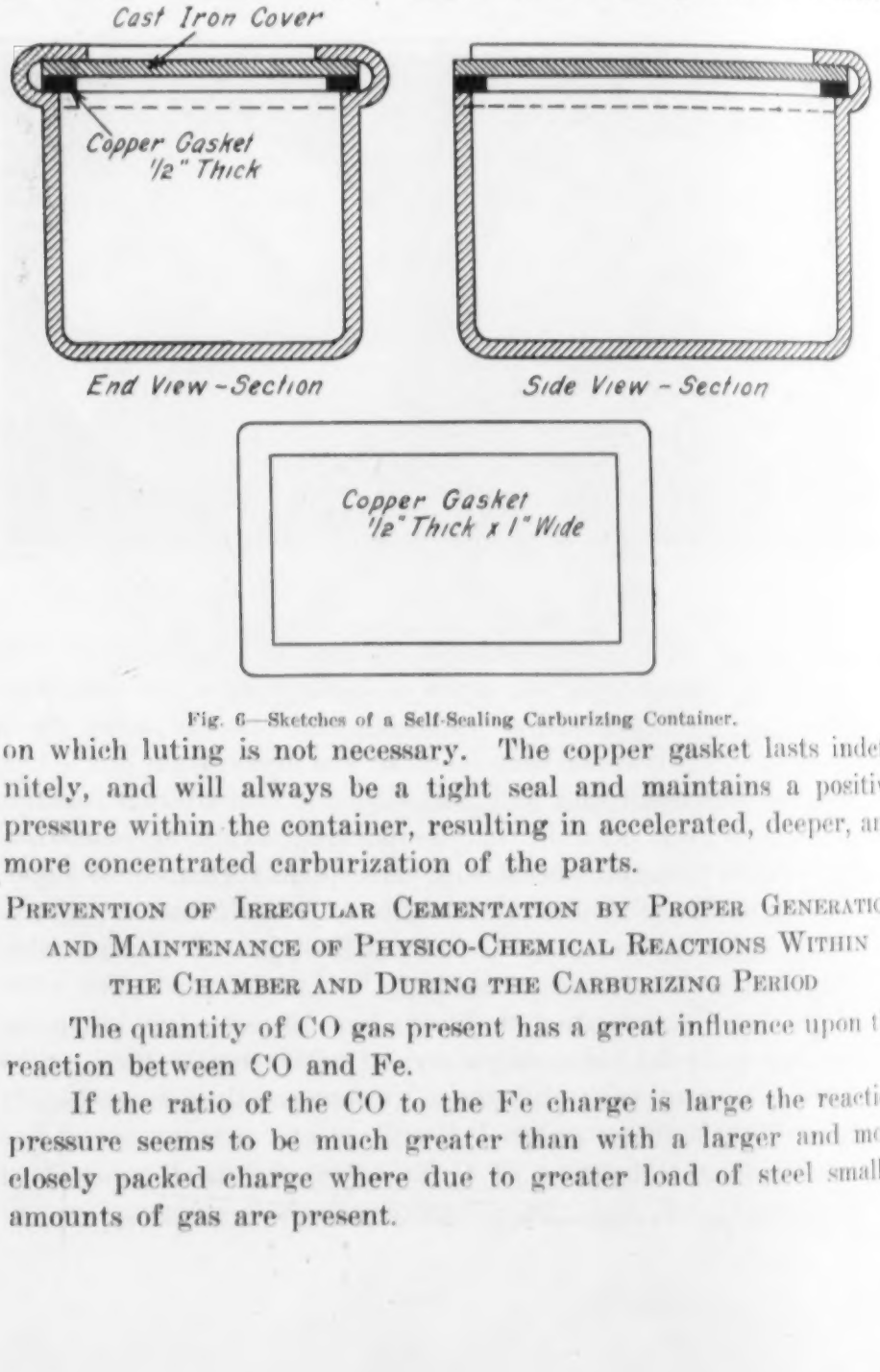


Fig. 6—Sketches of a Self-Sealing Carburizing Container.

on which luting is not necessary. The copper gasket lasts indefinitely, and will always be a tight seal and maintains a positive pressure within the container, resulting in accelerated, deeper, and more concentrated carburization of the parts.

Prevention of Irregular Cementation by Proper Generation and Maintenance of Physico-Chemical Reactions Within the Chamber and During the Carburizing Period

The quantity of CO gas present has a great influence upon the reaction between CO and Fe.

If the ratio of the CO to the Fe charge is large the reaction pressure seems to be much greater than with a larger and more closely packed charge where due to greater load of steel smaller amounts of gas are present.

Since by action of CO on Fe we form Fe_3C as per equation:

$$3\,Fe + 2CO = Fe_3C + CO_2$$

at temperature above 1290 degrees Fahr. (700 degrees Cent.) this Fe_3C will go into solid solution with iron.

Carbon monoxide (CO) concentration or the ratio $CO:CO_2$ is of course the most important factor influencing the process, and if ratio is large satisfactory cementation will occur.

If CO gas is not predominant and large amounts of CO_2 gas are in evidence oxidation of Fe_3C will take place as follows:

$$Fe_3C + 4\,CO_2 = 3\,FeO + 5\,CO$$

Fusible ash concentration of energizing compounds and irregular packing will cause the above reaction resulting in soft spots due to decarburization by CO_2.

Also Na_2CO_3, which melts at 1517 degrees Fahr. (852 degrees Cent.) and dissociates feebly at 1832 degrees Fahr. (1000 degrees Cent.), oxidizes iron at fusion heat of 852 degrees Cent. and an excess of Na_2CO_3 or its concentration is to be avoided. Another source of irregular carburization is the formation of loosely adhering Fe_3C by interaction of carbon and iron oxide $C + FeO$ at high temperature is accomplished by the presence of iron scale Fe_3O_4, which decomposes to form FeO and Fe.[5] Again the source of FeO may be a machined surface covered with an alkaline cutting compound, and the above reaction and formation of Fe_3C occurs. The loose Fe_3C so formed does not combine with iron or diffuse through iron to form a solid solution, but crumbles on the surface and contaminates the carburizing compound and dilutes its strength. A perfectly clean steel should be provided to obtain best results from carburizing.

Gas Carburizing and Prevention of Contact with Carburizing Compound and Residual Fusible Ash

From what has been said above it becomes evident that a purely gas pressure contact carburizing is the desirable process for quality results. To obtain this in the old style carburizing boxes and without radically changing the old process, a series of screens were made which keep the solid carburizing compound from coming in contact with the parts and permit the suspension of these parts. They may be made of copper. If made of steel or iron

[5]Physical Chemistry of Metals, by R. Schenk.

they soon become saturated with carbide, causing them to become brittle and weak after a few applications at the carburizing temperatures. A cylindrical type of such screen is shown in Fig. 7. Spacing and packing were no longer necessary and a simple filling of the carburizer around the screened part was the only care ex-

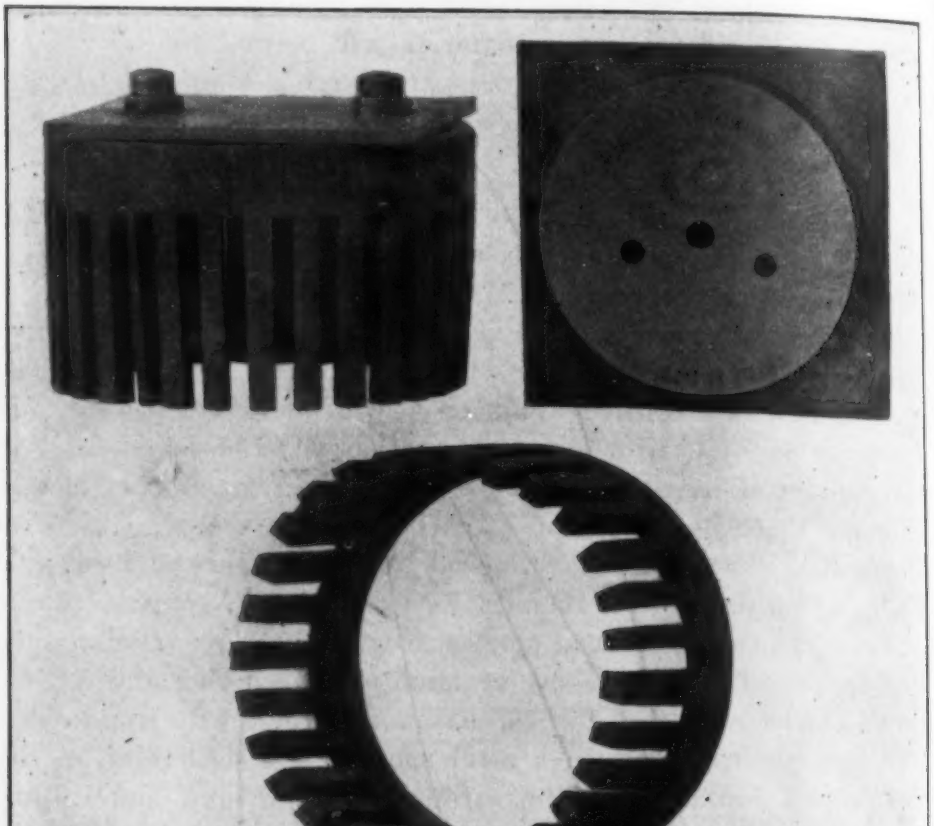


Fig. 7—Copper Ring Screens for Use in Carburizing Die Inserts. The Die Inserts are Suspended Inside of the Screen Ring and are Thus Kept from Contact with the Carburizing Compound.

pected of the operator. The screening out of the fine and pulverized carburizing dust became unnecessary, which naturally results in a decided economy. The improvements in the uniformity and depth of case were at once manifest and a greater concentration of carbide was procured. The surface of the parts treated (carburized) was lustrous and bright where formerly discoloration was obtained. Low carbon steels and medium carbon steels all react in the same manner and respond readily to the action of the CO gas.

It should be again stated that the materials must be in either the normalized or annealed state before subjecting them to the process in order to obtain the above described results. The abnormality or normality of the steel has not affected the results and satisfactory carburizing was entirely dependent upon:

(1) proper temperature and time
(2) arrangement of parts within the container
(3) kind of carburizer

Summary of Results and Discussion

The above described experiments and results establish the fact that consistently uniform carburizing can be achieved practically only by conducting the cementation process in a manner that permits the reaction between iron and carbon monoxide to take place under favorable or chemically correct conditions, which include—

1. Uniform grain structure of steel or iron, produced by heat treatment prior to carburizing.

2. Clean surfaces, free from scale and grease and matter, chemically active below or at carburizing temperatures, which chemical reactivity results in deleterious dilution of the CO gas.

3. Arrangement of articles so as to expose all parts of the surface uniformly to the carburizing gas (CO).

4. A container so sealed that a positive pressure is maintained therein during the period of carburizing.

5. A uniform temperature above the upper critical temperature which changes the iron to the gamma condition and produces a solid solution of carbide in gamma iron (austenite).

6. For partial or selective cementation, the use of solid copper protecting equipment in preference to any of the present methods, including copper plating.

Conclusion

In concluding, it should be restated that the irregularities in carburizing results enumerated in this report were traced back to the omission of a necessary step or a short cut in conducting the process as outlined, and steel made by the ordinary steel making methods will respond satisfactorily to cementation. Reheating for refinement of case and core, reheating for quenching and also quenching and tempering must be conducted as prescribed in the author's previous paper.[6]

[6] *Fused Salt Baths for the Prevention of Soft Spots in High Carbon and Carburized Steels*, Transactions of the American Society for Steel Treating, Vol. VII, January, 1925, page 22.

Discussion of Mr. Merten's Paper

Written Discussion:—By S. C. Spalding, Syracuse, N. Y.

This paper brings a little further light on the interesting and still somewhat obscure subject of normal and abnormal steel. Although at the present time, I would not want to go so far as the author has and deny that normal or abnormal steel existed, I do believe that a great deal of pure carburizing trouble is unjustly laid to the steel.

It is unfortunate that the author does not support his statements and conclusions by more actual experimental data.

The points made of having the parts to be carburized free from dirt and scale and in a normalized or annealed condition are good ones. The point made that carburizing by gas alone without contact between the pieces and compound is the most efficient may, I believe, be open to some question. The further point made that the boxes be so sealed that a positive gas pressure exists inside may have some bearing. Under ordinary conditions, however, with ordinary luting which is not gas tight, the experience is that good contact between pieces and compound is necessary. The use of a tray holding the pieces to be carburized as described in the paper unless a perfectly gas tight box were used, might not give good results.

Written Discussion:—By Samuel Epstein, Bureau of Standards, Washington,

Mr. Merten's paper is essentially a plea for greater care and watchfulness in carburizing, for thorough methods based on scientific study to replace the prevailing more or less antiquated practice. This stand is indeed timely and well taken. In the brief but prominent mention of the subject of normal and abnormal steel, however, the author has stepped on disputed ground. It is probably very true, as he states, that irregular case-hardening and the ensuing soft spots are more largely due to shortcomings in the carburizing and hardening operations than to abnormality of the steel. The responsibility for the results obtained in carburizing ought rightly to rest largely, if not entirely, on the carburizer, and ought not to be shifted hastily or lightly to the steel maker. Nevertheless, the carburizer cannot afford to neglect the factor of abnormal steel altogether, as the author infers he can safely do. In the paper the importance of preparing the steel for successful carburization by first putting it in the right structural condition is strongly stressed. Annealing prior to carburizing is even advocated, for castings, and hot-worked and cold-worked parts. Yet at the same time, the pronounced influence on both the depth and structure of the case, known to be exerted by abnormality of the steel, is judged to be of no consequence.

As a matter of fact, experiments made at the Bureau of Standards to test out this point, in preparation for this discussion, have shown that abnormality of the steel has a far greater effect on the depth and structure of the case than has the original state of the steel (cast, hot, or cold-worked). Indeed the answer to the allegation often heard that cold or hot working of the original steel has a harmful effect on the depth and structure of the case, seems to be that these factors have little or no effect, whatever.

The accompanying photomicrographs of the carburized structures of cast,

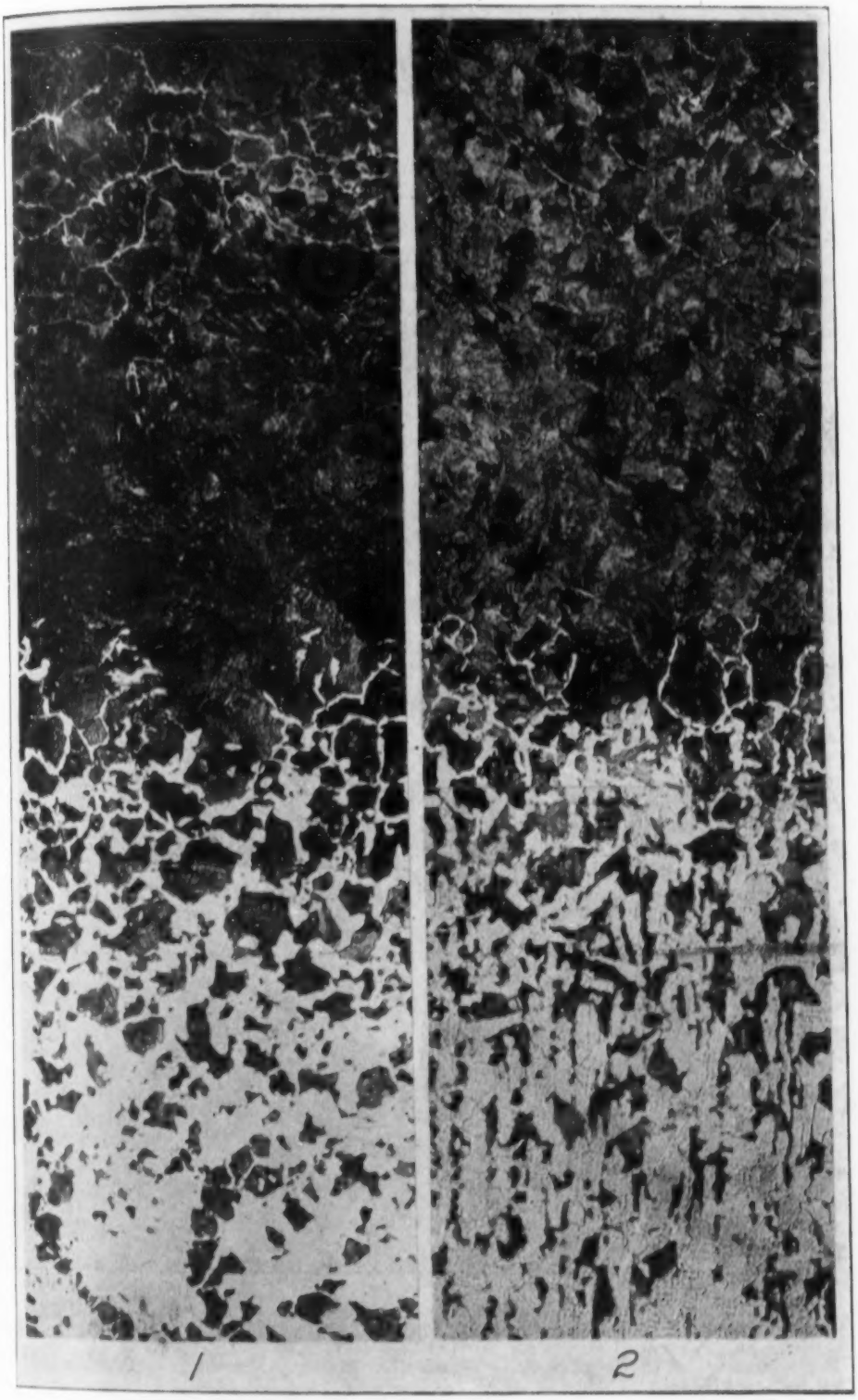


Fig. 1—Carburized Layer of 21x21-Inch Ingot. As Cast. 50X. Fig. 2—Carburized Layer of 2-Inch Round Bar from the Same Ingot. 50X. Both Specimens Show a Uniform and Normal Case.

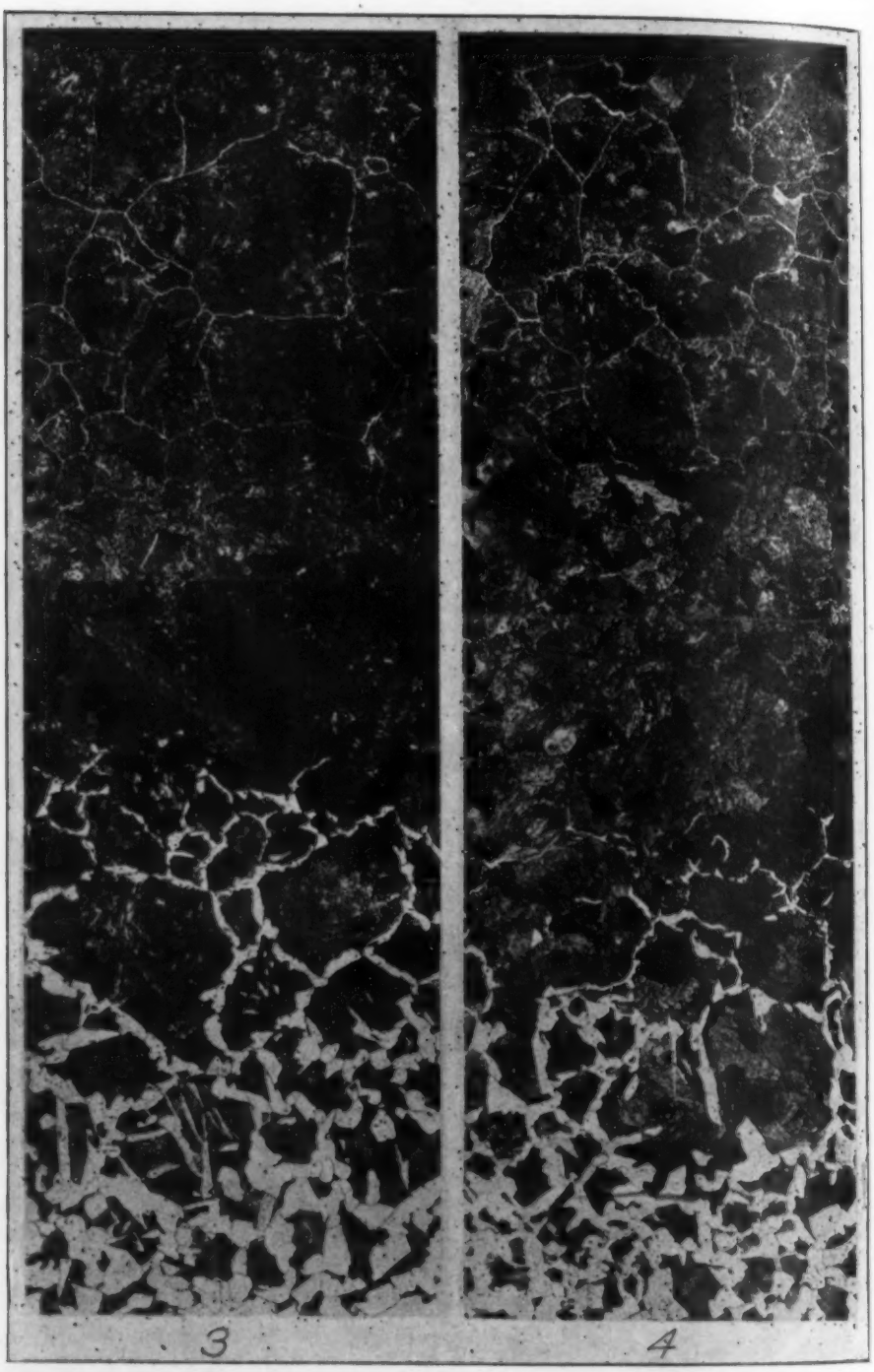


Fig. 3—Carburized Layer of a 1½-Inch Round Bar of Normal Steel. 75X. Fig. 4—Carburized Layer of the Same Specimen when Cold-Rolled to ½-Inch Flat Bar. 75X. Both Samples Showed a Uniform and Normal Case. There was no Evidence of Any Change in the Structure of the Case Produced by the Cold Rolling. Annealing Prior to Carburizing had no Effect.

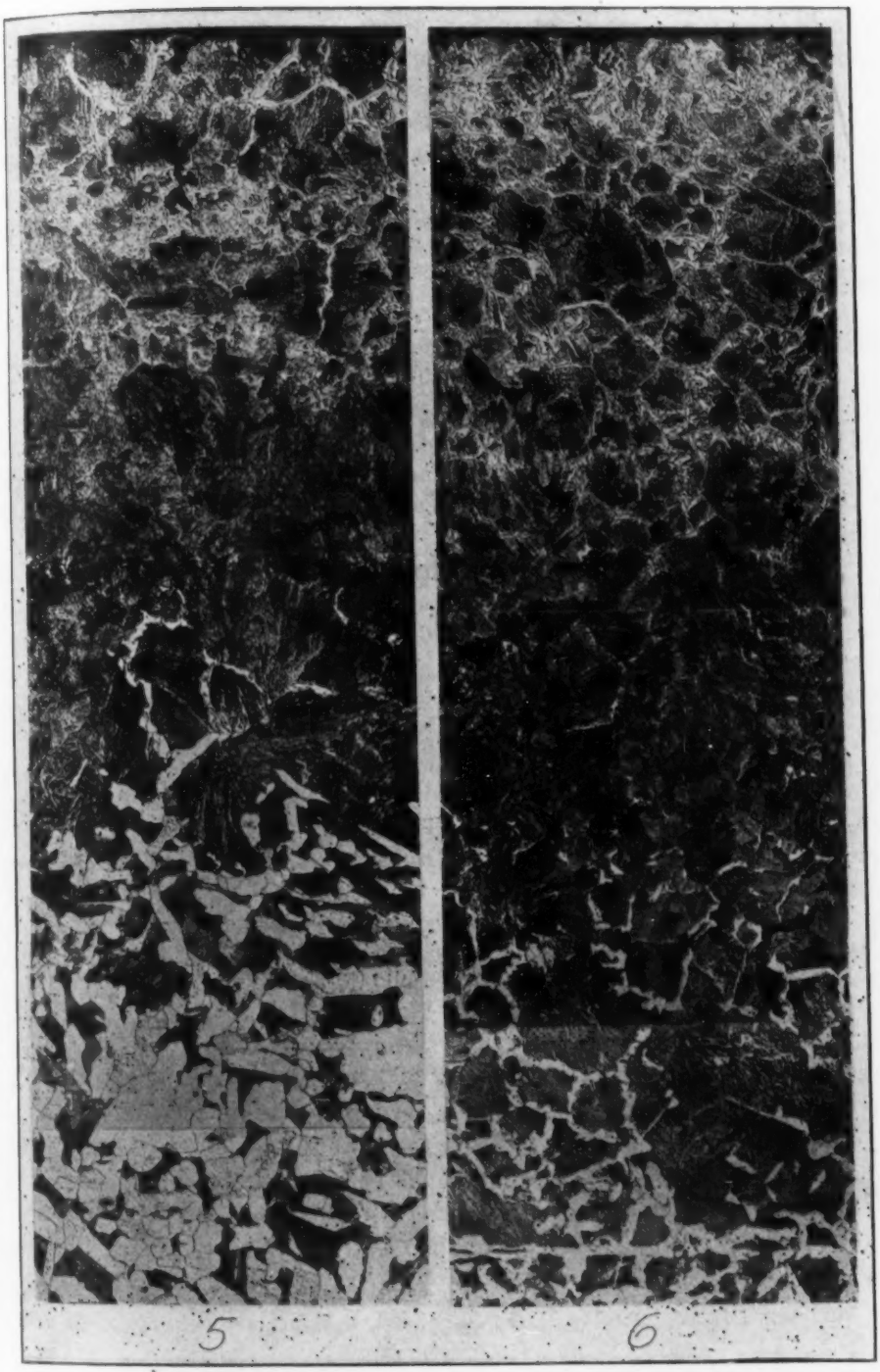


Fig. 5—Carburized Layer of 1x½-Inch Bar, Somewhat Abnormal. 75X. Fig. 6—Carburized Layer of Same Bar After Being Cold-Rolled to $\frac{3}{16}$ Inches Thick. 75X. Both Samples Showed the Same Type of Case. The Degree of Abnormality Did Not Seem to be Affected by the Cold Rolling. Annealing Prior to Carburizing Produced no Change.

hot-rolled, and cold-rolled specimens, were chosen as representative of four types of steel and over 25 specimens. All were carburized in the same pot under identical conditions.

Figs. 1 and 2 are photomicrographs of the carburized layer of a specimen from a 21 x 21 inch ingot as cast, and of the carburized layer of a 2-inch round rolled from the same ingot. The case was absolutely uniform and normal in both the cast and hot-rolled sample; there was nothing to distinguish between the two samples as far as the structure or uniformity of the case was concerned.

Figs. 3 and 4 are photomicrographs of the carburized layer of a 1.5-inch round stock of normal steel, and of the carburized layer of a specimen from the same bar carburized after cold rolling from 1.5-inch round to 0.5 inch flat. The case was absolutely uniform and normal in both samples. The severe cold working of the cold-rolled sample had no noticeable effect on the uniformity or structure of the case. Annealing of the cold-rolled sample prior to carburizing produced no effect upon the appearance or structure of the carburized layer.

Figs. 5 and 6 are photomicrographs of the carburized layer of a 1 x $\frac{1}{2}$-inch somewhat abnormal bar, and the carburized layer of a specimen from the same bar cold-rolled from $\frac{1}{2}$-inch width to $\frac{3}{16}$-inch width. The case was uniform in both samples, with the same degree of abnormality in the original sample persisting in the cold-worked sample. Annealing prior to carburizing had no effect.

The speaker considers that it is well established from the work of the Bureau of Standards and others that most abnormal steels give a shallower case than normal steel, and also, there is evidence that abnormal steel is more prone to give soft spots on hardening than normal steel. These facts should be sufficient reason for the carburizer to keep himself informed on the subject of normal and abnormal steel, to use this information in his work, and not to leave abnormal steel out of his calculations, as is advised in this paper. On the other hand, it does not appear that the author has proved adequately enough that the original state of the steel (cast, hot, or cold-worked) may have an injurious effect on the carburized layer, to justify the carburizer in going to the expense of annealing prior to carburizing. Theoretically, it does not seem plausible that the original structural condition of the steel as produced by working can have much effect on the uniformity or structure of the carburized layer and the photomicrographs herewith shown, also indicate that there is no effect. Annealing of articles for carburizing may serve some other useful purpose, but as shown above, it would be of no benefit on the uniformity or structure of the carburized layer.

Written Discussion: By B. F. Shepherd, assistant metallurgist, Ingersoll-Rand Co., Phillipsburg, N. J.

Equilibrium diagrams can be obtained to show the relation between carbon, carbon monoxide, and carbon dioxide. McCance, in the *Journal* of the Iron and Steel Institute, page 439, 1919, has shown this relation and his results are given in Fig. 1. Theoretically, the composition of the mixed gases at any temperature can be ascertained by passing carbon dioxide

over carbon. The equilibrium curve given shows that at a temperature of 650 degrees Cent., the composition of the mixed gases under equilibrium conditions will be 61.5 per cent carbon dioxide and 38.5 per cent carbon monoxide.

A simple experiment was performed to show that highly strained material will carburize as uniformly as unstrained material, and to the same depth. Three pieces of 1-inch square stock, S. A. E. 1020 were placed separately in a testing machine and a load of 125,000 pounds placed on a half inch round bar, previously placed on top of the test piece, deforming it, as shown in Fig. 2. Two of these bars marked A and B were in the hot-rolled

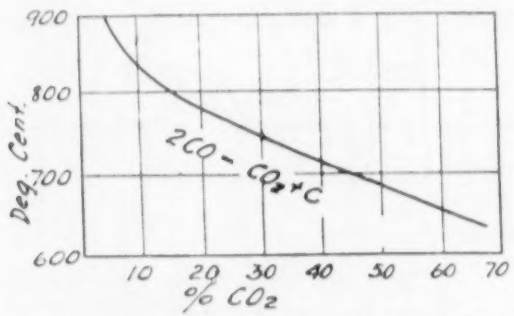


Fig. 1—Equilibrium Curve Showing Relation Between Carbon, Carbon Monoxide and Carbon Dioxide. *After McCance.*

condition as received from the mill. The other marked bar C, was ground to remove all scale, etc. They were carburized for 18 hours after heated through at 1625 degrees Fahr., and allowed to cool in the pots. Bars B and C were reheated in lead to 1420 degrees Fahr., and cooled in brine. Each bar was cut longitudinally along the center axis, normal to the depression formed by the half inch bar. Half of each bar was polished for metallographic examination and the other half broken as shown in Fig. 2. The depth of case as shown in the fracture and microstructure was the same through the entire surface. The highly strained material carburized to the same depth as the unstrained material. The hypereutectoid cementite was of the same concentration in both strained and unstrained material. This is true for both, "after carburizing" and "after hardening" test pieces under examination of the microscope with low and high magnification.

With reference to the statements made as to scale on the seventh page of Mr. Merten's paper, test bars B and C mentioned above, were carburized with and without scale, respectively. The depth of case obtained on each of these test pieces was the same. Attention is also directed to the thirteenth page, of the second progress report of the Bureau of Standards on "Investigation of the Influence of Character of the Steel used on the Results obtained in Carburizing." Their micrographs 5 and 6 show, respectively, the structure of the outside of the bar carburized without removing the rolling scale and the interior of the same bar, as carburized. The depth of case obtained is essentially the same. The writer does not mean to imply that he recommends carburizing without removing the scale.

A piece of 1-inch square S. A. E. 1020 steel was carburized after being protected, as shown in Fig. 3. The bar was ground all over

and the face placed against the copper slab, ⅛-inch thick by 1 inch wide, was ground on a surface grinder, the opposing face of the copper slab also being ground in the same manner. The set screw was used to hold the copper in very close contact with the steel. At the opposite end the copper slab was ⅛-inch from the steel. Half of the bottom face of the bar was given an electrolytic copper deposit of a thickness of 0.0003-inch. The bar was carburized at 1625 degrees Fahr., cooled in the pot, reheated in lead to 1420 degrees Fahr., and quenched in brine. The bar was cut along a center longitudinal axis, normal to the face protected by the copper slab. Half of the bar was polished for metallographic examination and the other half broken for fracture. Fig. 3 shows the depth of hardened case at various

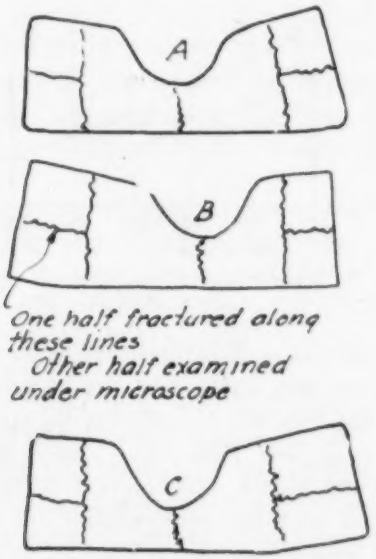


Fig. 2—Sketch of Specimens Tested for the Purpose of Determining the Effect of Cold-Work Upon the Carburizing of 1-Inch Square Bar Stock. Specimen A—"As Rolled" and Carburized. Specimen B—"As Rolled," Carburized and Hardened. Specimen C—"As Rolled," All Scale, etc., Removed with Grinding Wheel, Carburized and Hardened. All Specimens had same Depth of Case in the Strained and Unstrained Sections.

intervals along the bar. Under the microscope, there is found a slight increase in carbon content where the copper slab and the steel were in most intimate contact. The carburizing gas penetrated around the set screw and carburized a few of the top threads. The metallographic examination corroborates the examination of the fracture. The section protected by the electrolytic copper deposit was entirely free from any increase in carbon content.

The pressure of gas under constant volume, heated to 1650 degrees Fahr., from atmospheric temperature increases to about 60 pounds absolute pressure, or 4 atmospheres, according to a well known law (Gay Lussac's) of physics. Giolitti has shown that the depth of case increases greatly with increase in pressure of the carburizing gas. The carburizing box shown by Merten must

be capable of reproducing the same pressure or the results will be very uniform. The luting of carburizing boxes is to prevent ingress of the

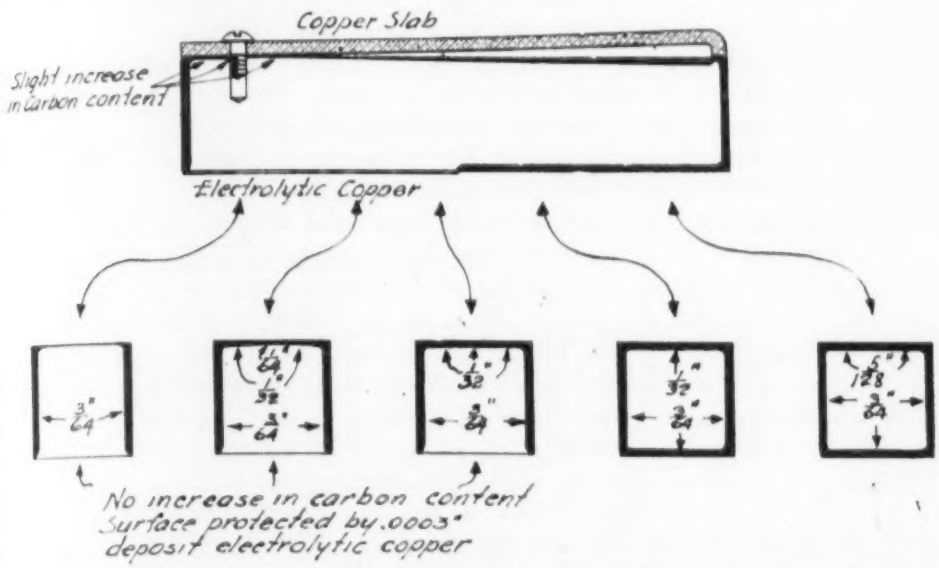

Copper Slab
Slight increase in carbon content
Electrolytic Copper
No increase in carbon content
Surface protected by .0003" deposit electrolytic copper

Fig. 3—Sketch Showing the Manner in which Experiments were Conducted by the Writer for the Purpose of Determining the Amount of Carburization Obtained when a Steel Specimen 1-Inch Square is Carburized, Using a Copper Slab and Copper Plating as Shown.

atmosphere rather than to render the box gas tight. The constant evolution and escape of gas also prevents entrance of air.

Oral Discussion

J. D. Gate: This is a most interesting paper. I might say, however, that our practice, and we have had very much practice in this line, has shown distinctly that no changes in the state of normality can be effected whether the steel is carburized in a basket or under gas pressure. It is true, that using different temperatures we are able to change the grain size, but there are several other indicators besides grain-size by which to judge the normality of a steel. We have the core, which, after proper annealing, will always have a definite appearance. We have the size of cementitic grains and their shape in hypereutectoid zone. These indicators cannot be changed by carburizing. No matter how we carburize, we will get the same thing. If we happen to carburize at 1850 degrees Fahr., as it is our practice in certain cases, the grain-size and penetration of carbon will be the same in both cases, i. e., normal and abnormal steels, but the appearance of core and cementitic mesh will be left unchanged.

It is necessary to mention that we are usually talking about abnormal steels as belonging to the carburizing grade. I believe that we have to get a little broader conception of the facts connected with normality, I would call it relative normality, which has to be extended over the whole field of steels.

Maybe it will sound strange to you, gentlemen, but it is a fact, that when buying spring steels, or high carbon steels, we always have to pay attention to their normality. It is strange, but a steel having a high percentage of carbon may be very abnormal or normal. Those who have had some experience with high carbon tool steels, or straight carbon steels, most probably have had experience with the difficulty of hardening them. The situation is the same with, say, springs. Often we have perfectly sound steel in every respect, and when using a correct heat treatment fail to be able to refine the grain. After thermal treatment it will give the desired Brinell hardness but no efforts will reduce the grain size and eliminate crystalline fracture.

It was not exactly clear whether the changes in carburizing practice were connected with the elimination of soft spots. In our practice, and I base my remarks, at the present time, on the practice of one of the large roller bearing plants, it was found that no matter how abnormal or normal is the steel, if it contains a little chromium, no troubles will be experienced with the hardening.

W. J. MERTEN: Gentlemen, there seems to be an entire absence of harmony among the adherents of the abnormal steel hypothesis as to what is meant by abnormal steel. I seem to have one interpretation of what they mean by abnormal steel and Mr. Epstein from the Bureau of Standards has another one, and perhaps to someone else in the audience it means something different. Oxidized steels can be eliminated by proper raw material inspection and should be classed as unsatisfactory for any purpose except remelting. There is certainly no need to subject materials to carburizing in order to establish their defects of such character.

It has been stated that aluminum deoxidation of steel produces abnormality. It certainly cannot be argued that we at our plants obtain steel from the steel mill more carefully made than that obtained by any other plant. I also wish to point out that the experiments described are not laboratory experiments but plant experiences and practice extending over a time of at least 2 years, following the establishment of these facts by preliminary tests on a laboratory scale. I wish to state that I am using the heat treating department as my laboratory, with very gratifying results.

I would also emphasize that we at the W. E. & M. Co. are not in the habit of giving publicity to laboratory experiments bearing upon plant practice until such practice has thoroughly established itself and confirmed laboratory results, on a production scale.

Regarding photomicrographs shown by Mr. Epstein of carburized cold rolled and cold-worked steels, the few cases investigated do not establish proof that structural conditions prior to carburizing are essential for uniform results. The fact that the Bureau of Standards has found irregularities which they have attributed to so-called abnormal steel, defeats his own defense, and I believe the answer can be found as I have stated in my paper in "the omission of a step" in the correct carburizing practice for uniform and consistent results.

In order to answer the speaker who advocates an extension of tests for

(*Continued on Page 1004*)

THE DUROMETER—AN INSTRUMENT FOR TESTING HARDNESS*

By Dr. Albert Sauveur

Abstract

This paper describes a new instrument used in determining the hardness of metals. The author has described the machine and the manner in which it functions.

THE apparatus called "Durometer" briefly described in the following pages has been designed for testing the hardness of metals and other hard substances.

It consists of a casting A, supported on a wooden base B, the specimen to be tested C, being held in place at an angle of 45 degrees by a screw D and adjustable disk E.

The plate F has a groove through which a portion of the surface of the specimen C is exposed.

To the iron base an upright G is attached. It has a groove H at its lower end, while at the upper end it carries a stage I, iris diaphragm J, and steel ball K. The apparatus is supplied with levelling screws L, and swinging rod and pointer M. A glass plate N rests on the board and upon this plate is placed a sheet of graduated paper, covered with a sheet of carbon paper, O.

On opening the iris diaphragm, the steel ball falls upon the specimen and rebounds through grooves in plate F and upright G, and upon the glass plate N, recording by a black dot on the graduated paper O the exact position of its fall. It is then caught in box P.

It is obvious that the rebounding impulse communicated to the ball must increase with the hardness of the sample, and that the readings automatically recorded on the scale may be taken as a measure of the hardness of the samples, provided the precautions to be described have been observed. These readings will be referred to as Durometer Numbers.

The following requirements necessary to obtain satisfactory results will be readily understood:

1. *Levelling.* It is evident that the surface of sample ex-

(*) Since the presentation of the paper at Cleveland in September 1925, the instrument has been modified and the description has been revised accordingly.

A paper presented before the Hardness Testing Symposium of the Cleveland Convention of the Society, September 1925. The author, Dr. Albert Sauveur, honorary member A. S. S. T., is professor of metallurgy, Harvard University, Cambridge.

posed to the impact of the ball should be exactly at an angle of 45 degrees. It is therefore essential to level the instrument very accurately, by means of the levelling screws and hanging rod and pointer.

2. Steel Balls. In order to obtain comparative results when different steel balls are used, the latter should be of the same weight and hardness. Their hardness may be tested by dropping

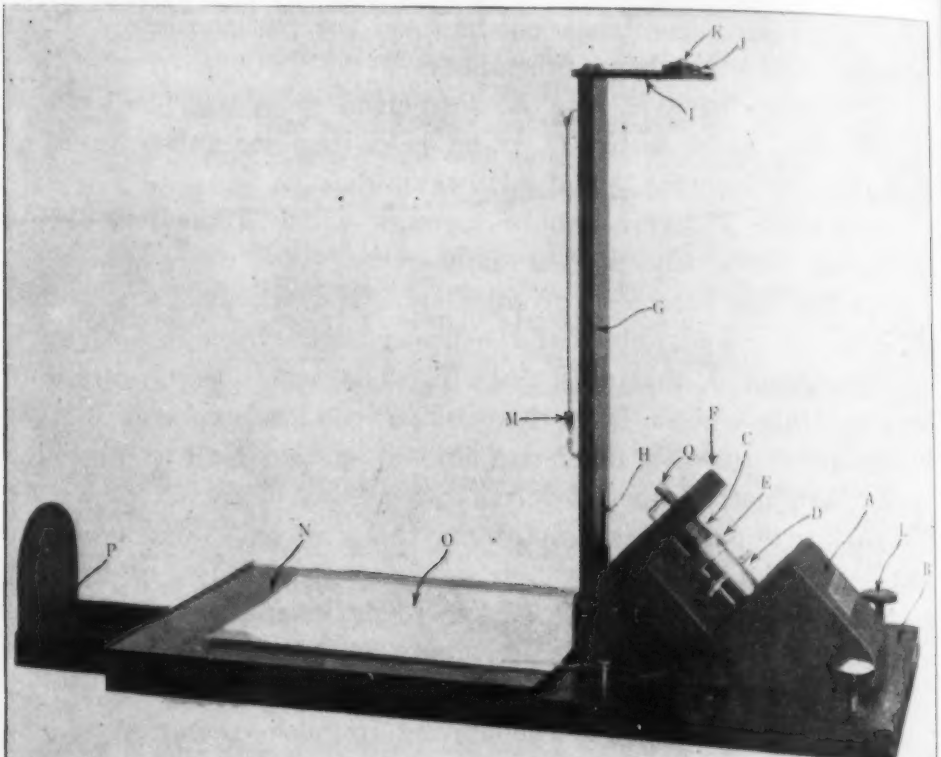


Fig. 1—Photograph of the Durometer. A—casting; B—wooden base; C—specimen; D—screw; E—adjustable disk; F—plate; G—upright; H—groove; I—stage; J—iris diaphragm; K—steel ball; L—leveling screws; M—swinging rod and pointer; N—glass plate; O—carbon paper; P—box; Q—pointer for locating position upon which ball will fall.

them in the Durometer, on a piece of plate glass. Those only having identical rebound should be used. The 10-millimeter balls manufactured for the Brinell testing machines are remarkably uniform, there being no difficulty in obtaining balls of substantially the same weight and same hardness.

3. Size of Samples. For small samples the rebound of the ball increases with the thickness and mass of the sample. With samples not less than one inch in thickness and one inch in width,

however, this action becomes negligible. It is recommended, therefore, that the samples tested in the Durometer be not less than one inch thick, and preferably also not less than one inch in width. When it is necessary to test thinner and lighter samples, the sample may be backed by a steel plate not less than one inch thick, nor less than one inch in width. This tends to produce rebounds identical to those of specimens more than one inch thick, especially if the backing plate has substantially the same hardness as the sample tested. Or the recording sheet on the glass plate may be shifted so as to secure identical readings, for different rebounds. A graduated rule on the side of the table could indicate the proper position of the recording sheet for thickness of samples less than one inch. This latter method appears to be the most satisfactory one.

Of course, when it is desired to ascertain the relative hardness of thin samples of uniform dimensions, this influence of thickness and mass need not be considered, it being sufficient to drop the ball from a constant height.

4. Surface Finish. Rough surfaces are likely to yield irregular results, it being difficult to check satisfactorily the readings. It is essential, therefore, that the surface of the sample to be subjected to impact should be smooth. Grinding with a fine emery wheel or emery paper generally suffices.

5. Releasing the Ball. The iris diaphragm should be opened gently and gradually, because too sudden a release of the ball would result in its starting to fall from a slightly greater height (its center of gravity lies five millimeters above the diaphragm) which in turn would result in a slightly greater rebound and higher Durometer reading.

6. Locating the Fall. When the ball is permitted to fall near the edge of the sample the rebound is generally less. This is the reason narrow specimens (less than one-half inch in width) generally give shorter rebounds than wider ones tested in the center. The samples, therefore, should be so held that the ball will not strike near the edge. The instrument is provided with a pointer Q, by which the exact position upon which the ball will fall can be located.

7. Repeated Testing. When attempting to secure several Durometer readings from the testing of the same sample, the ball should not be allowed to fall twice on the same spot, because the first blow produces a slight cold working of the metal which is

therefore locally hardened, resulting in greater rebound if again tested.

The conditions necessary to obtain satisfactory results may be therefore briefly summarized as follows: (1) Careful levelling of the apparatus; (2) use of balls of identical weight and hardness, if it is desired to compare results obtained with different

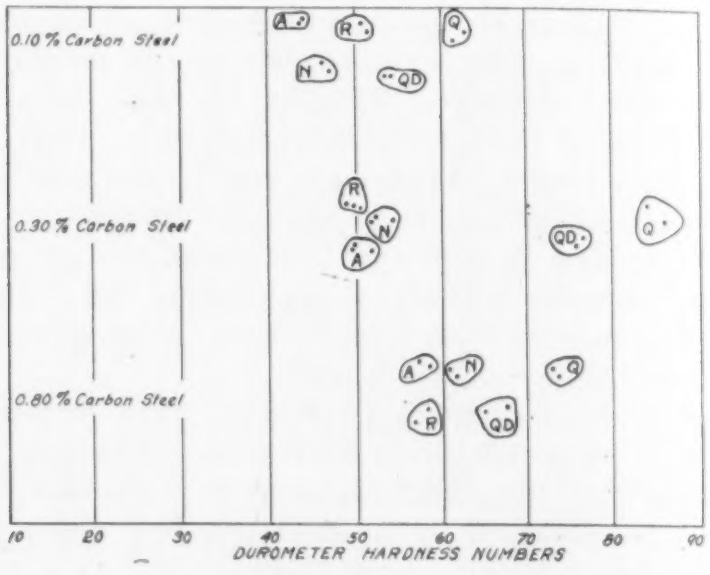


Fig. 2—Graph Showing the Durometer Hardness of Three Different Carbon Steels.

balls; (3) gradual opening of the iris diaphragm in releasing the ball; (4) use of specimens preferably not less than one inch thick and one inch wide; (5) the surface to be tested should be smooth; (6) preventing the ball from striking near the edge of the specimen; (7) preventing the ball from striking twice on the same spot.

When these precautions are taken, there should be no difficulty in checking Durometer readings within two divisions of the scale. The results obtained in measuring the hardness of three kinds of steel, after various treatments, are shown in Fig. 2 and are tabulated below. Samples 1 inch in diameter and 1 inch thick

Carbon %	R	A	N	Q	QD
0.10	51-51	44-44	47-47	62-62	54-54
0.30	50-50	50-50-52	52-52-53	84-86	76-76
0.80	67-68	68-69	71-72	80-83-83	75-77

were used, the ball being dropped from maximum height. The

(Continued on Page 1000)

PROGRESSIVE CARBURIZATION IN ROTARY ELECTRIC FURNACES

By H. E. Martin

Abstract

Development of heat control on oil burning furnaces and the limitations of such equipment as encountered at Dodge Brothers, Inc., is discussed in this paper, together with the reasons why electrical heat was selected for additional carburizing and heat treating furnaces.

A description and photograph of the rotary carburizing furnaces is followed by the cycle of operations, the heat control arrangement, and advantages noted after twenty-seven months' operation on two of the furnaces.

One year's production and power consumption on two rotary carburizing furnaces is tabulated, showing the gross and net pounds produced per kilowatt hour.

HEAT treatment of steel at its inception at Dodge Brothers, Inc., required that expert and individual attention be given to oil burning furnaces and the material being treated. The quality of the work turned out was a function of the fireman (burner tender) and foreman or expert, with more or less aid of the pyrometers. Gradual development work with the thermocouple and temperature indicator, leading to automatic recorders, threw more responsibility on these instruments. The practical man or foreman of former days was partially replaced, so far as the heating cycle was concerned, by a technical man situated in a remote control room with automatic temperature recorders, designating by a system of lights on the furnaces, the progress of the heat and time to discharge. Heat treating costs were lowered, due to more uniformity, but the hazard of poor oil and the untrained fireman still remained.

Automatic burners were consequently developed to take care of the undesirable human element. The amounts of air and oil through all burners were regulated by a solenoid automatic-valve which was actuated by the furnace recorder setting. Theoretically, this should result in 100 per cent of the steel being correctly heat treated. Actually, with technical and practical supervision and automatic heat control, rejections did occur from time to

A paper by H. E. Martin, member of the Society and assistant metallurgist, Dodge Brothers, Inc., Detroit.

time and in the carburizing process irregular carbon penetration occurred occasionally.

The reasons for these irregularities and disadvantages of this system are as follows:

1. Improper heat application to the stock in the furnace, that is, heat absorption by the steel from the brick hearth and wall and direct flame in certain instances.
2. The presence of foreign matter in the fuel oil such as tar, dirt, water, etc.
3. High cost of maintenance, frequent rebuilding, requiring additional furnaces to take care of production requirements.
4. Question of oil supply and cost in the future.
5. Floor space—too much floor space required per automobile produced.

To take care of these difficulties, all available methods of heat production were investigated, including city gas, producer gas, oil, and electricity. For the following reasons electrical heat was chosen to attain highest quality work in face of high production at minimum cost:

1. Absolute control of heat input and direct application of this heat to the steel. Rejections on quenched and drawn forgings reduced to a minimum and the carburizing process reduced to an absolute time cycle with no intermediate sampling. It might be added that rejections result in a break in the continuity of the production flow of parts which in turn interferes with production schedules and resultant loss of time on later machining operations.
2. Flexible heat control—In pusher, conveyor, or rotary hearth furnaces, the charging end may be carried at a considerably higher temperature than the desired temperature, thereby, insuring more rapid heating. In some cases, three separate electric circuits are used resulting in three heating zones.
3. Low maintenance—Dodge Brothers' experience over a period of more than two years shows the maintenance costs to be lower, due primarily to lack of excessive temperatures and oxidizing conditions, such as

exist in the combustion chamber of the oil-fired furnace. Contrary to expectation, the 80-20 heating elements are not adversely affected by the reducing atmosphere of the electric furnace.

4. Working conditions improved; lack of smoke; better insulated furnaces providing more desirable working condition for the men.

5. Cost and maintenance incidental to handling of fuel oil not present.

6. Better assurance of future supply and present source of fuel.

7. Low heat loss due to thick insulation and lack of flues.

8. Decreased labor cost.

9. A combination of the foregoing or increased production per furnace.

Installation

The electric carburizing furnace installation consists of three rotary furnaces having the following dimensions:

Outside diameter	26 feet 3½ inches
Height above floor level	13 feet 2 inches
Distance below floor lever	5 feet 8 inches
Outside diameter of the rotating table	22 feet 8 inches
Inside diameter of the rotating table	12 feet
Area of table	270.8 square feet
Total loaded weight of rotating tables	60–70 tons

The rotating table is supported by ninety-one 1½ inch steel balls riding in a hardened gear race, also supplemented by eight dead eyes and rollers riding on a circular track. The table is driven by a shaft projecting up through the center of the furnace on top of which is mounted a 6-foot cast gear. This table is driven by a 1-horse power 220-volt motor operating through a speed transformer which gives a predetermined table speed of 10½-13½ and 15⅙ hours per revolution respectively in the three furnaces. The table is equipped with 27 alloy bucks or saddles equally spaced, 26 of which are active. These alloy bucks support the work 7 inches above the hearth, thereby, facilitating loading and unloading of the boxes by means of the elevating trucks and allowing the heat to strike the under side of the boxes.

The cycle of operation is as follows: The total carburization time cycle is divided by the 26 active piers which gives the time cycle for charging and discharging one pier of carburizing boxes.

After removal of a carburized charge, the furnace operator, by pressing the motor control button, starts the rotation of the table which moves forward until the 27th or empty buck automatically stops and indexes into position in front of the charging door. Five boxes are loaded by an elevating truck and this charge remains in the same position until the next cycle of operations. A baffle wall between the discharge and charging doors insulates the ingoing boxes from the boxes ready to be removed. The loading of the furnace is accomplished by raising from the loading platform 5 carburizing boxes 16x11½x8¾ inches on the elevator arms of an electric truck. The truck moves into position in front of the door, the arms are raised to the proper level, the door is opened by compressed air cylinder, and the truck moves forward, the arms straddling the pier or buck. The arms are lowered, depositing the boxes on the buck and the truck backs away from the furnace.

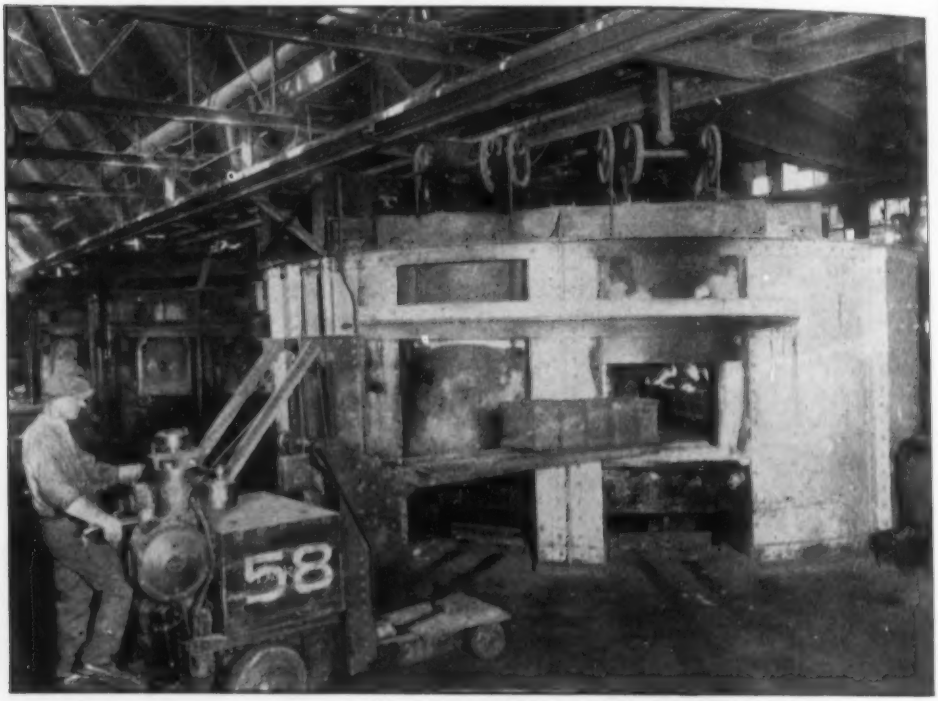


Fig. 1—Battery of Three Resistor Type Rotary Electric Furnaces Used for Carburizing Automobile Parts.

Each furnace is powered with 500 kilowatts made up of five-100 kilowatts, 220-volt, 3-phase circuits, arranged for 3-point control. The setting on three recorders control these circuits through their respective thermocouples, the recorders actuate relays which control the input switches. The first thermocouple, approximately 10 feet from the loading door controlling two-100 kilowatt circuits, is set for 1725 degrees Fahr. The second, approximately ⅓ the travel is set at 1700 degrees Fahr. and controlling two 100-kilowatt circuits, and the third, close to the discharging door, controlling one 100-kilowatt circuit and set for 1650 degrees Fahr. Our experience has shown that the higher temperatures on the charging side hastens the heating time of the boxes without danger of overheating. Approximately 1½ hours are saved in the cycle by this method. The heating elements suspended from both side walls are 80-20 nickel-chromium ribbon operating at a density of approximately 8 watts per square inch, give a maximum temperature on the ribbon of approximately only 100 degrees Fahr. higher than that registered on the thermocouple.

Twenty-seven months experience with two of these rotary furnaces have brought out the following facts:

1. They have produced the work which formerly required 20 oil-fired furnaces, with a 10x11 foot floor space necessary for each furnace.
2. The labor cost is ⅗ of the former installation.
3. The quality of work turned out approaches the ideal condition, i. e., uniform penetration of carbon which means practically no scrap in subsequent operations.
4. Continuous process, eliminating costly accumulations of semi-finished parts.
5. The production obtained and power consumed in one year from two of the furnaces follows:

Total number of boxes in furnaces..	168,730
Gross weight of boxes and stock in pounds	27,728,656
Net weight of stock in pounds	7,712,176
Kilowatt hours consumed	3,681,200
Gross pounds per kilowatt hours ..	7.53
Net pounds per kilowatt hours	2.09

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON—PART I

By F. T. Sisco

Abstract

The present paper, the first of the series, discusses in an elementary way some of the fundamental concepts necessary to a complete understanding of the constitution and structural changes of the alloys of iron and carbon. Included in the fundamentals are simple crystallization, saturation and equilibrium, crystallization of metals, orientation and cleavage, crystal structure, amorphous solids, allotropy, and the allotropy of iron.

TO the physical metallurgist or metallographist the terms steel and cast iron refer to a series of alloys[1] of the element iron (chemical symbol, Fe) and the element carbon (chemical symbol, C). In an elementary discussion of the constitution of steel and cast iron it is necessary, for the present, at least, to neglect the other common elements always present:—silicon, manganese, sulphur and phosphorus—and the alloying metals intentionally added:—nickel, chromium, vanadium and others. Consequently in this and the next few succeeding papers of this series we will confine our discussion to the alloys of iron and carbon, postponing the description of the occurrence and influence of the other elements until the nature of the simple alloys is thoroughly understood.

To simplify discussion we will consider steel to be an alloy containing 0.01 to 1.70 per cent carbon. In cast iron the carbon

[1]In a strict sense the use of the word alloy to refer to the iron carbon series is incorrect. Alloy postulates two or more metals. Carbon is a non-metal hence its various structural combinations with iron could not correctly be called alloys. In strict terminology the word compounds (not in the same sense as chemical compounds) would be justified. However, usage of the term iron carbon alloys occurs in practically all standard texts on metallography and so will be retained in this series.

The author of this article, F. T. Sisco, is metallurgist, with the Air Service, U. S. Army, McCook Field, Dayton, Ohio.

percentage will range between 1.70 and 6.67 per cent. The reason for this arbitrary division will be apparent later.

In a discussion of such an involved nature as the constitution of steel and cast iron we must necessarily proceed from the simple to the complex. Consequently the present article will take up the fundamental concepts so essential to a clear understanding of the iron-carbon diagram and to the structural and physical changes promulgated in the iron-carbon alloys by thermal treatment. The first of these is crystallization.

Simple Crystallization

If we add a teaspoonful of sugar to a tumbler of water and stir, the sugar dissolves. After this operation, instead of having the liquid water and the small, white, solid particles of sugar we have only one substance, a liquid which to all appearances is water. The sugar has gone into solution. If we disregard the sweet taste we have no physical means of identifying the sugar dissolved in the water, the liquid in the tumbler looks like water, it feels like water to the touch, a drop examined by the microscope fails to reveal the presence of anything except a liquid that apparently is water. The sugar has now lost its identity as a white, crystalline solid. It is in solution, in molecular dispersion in the water. In other words, the sugar has broken up into molecules which are so small and so uniformly distributed that they cannot be identified by means (disregarding taste) of our senses. Yet we know that the sugar is there because we can detect it by chemical analysis or recover it, in part at least, by a process known as crystallization.

If we let the tumbler of liquid stand for several weeks, or if we heat it to the boiling point we evaporate the water. Soon we reach a stage whereby small, white, solid particles of sugar appear on the bottom of the tumbler. If we let the hot solution cool undisturbed, more of these white particles appear. If these particles of sugar are examined closely with a magnifying glass it will be noted that they are more-or-less regular in shape and form. These small particles which are bound by regular plane surfaces are known as *crystals* and the process by which they are formed from solution is known as *crystallization*.

Saturation and Equilibrium

Let us again add a teaspoonful of sugar to a tumbler of

water and stir until it is dissolved. The result is a solution of sugar in water. If we add another teaspoonful of sugar and stir, it too will dissolve. In other words, the water will hold more than one teaspoonful of sugar in solution, consequently we say that it is *undersaturated.*

Let us continue to add sugar little by little, stirring vigorously after each addition. Soon we reach a point where no more sugar will be dissolved. Any more sugar added will sink to the bottom of the tumbler and remain there as white, solid particles of sugar. When we reach the point where no more sugar will dissolve we say that the solution is *saturated.* Assuming the temperature (and pressure) to be constant there is a definite amount of sugar which will dissolve in a definite amount of water to form a saturated solution. This quantity is always the same. Now, if X grams of sugar saturates Y grams of water, then with constant temperature and pressure, X is in *equilibrium* with Y. Adding water disturbs the equilibrium and results in an undersaturated solution. Consequently more sugar must be added to restore the equilibrium and again produce a saturated solution.

Let us add sugar to the tumbler of cold water until no more will be dissolved. Then let us add one teaspoonful more. This teaspoonful will settle to the bottom of the tumbler. Now we shall heat the water, stirring vigorously meanwhile. The sugar on the bottom slowly goes into solution and we again have a clear liquid which has the appearance of water. From this experiment it is clearly evident that the water will hold more sugar in solution when hot than when it is cold.

Thus we see that for each degree rise in temperature it takes a little more sugar to saturate the solution. Varying the temperature affects equilibrium conditions with respect to the amount of sugar which will dissolve in the water.

If we now let the hot solution cool undisturbed, solid, white particles of sugar begin to crystallize out and settle to the bottom of the tumbler. When the solution reaches room temperature the added teaspoonful of sugar is again on the bottom of the tumbler.

This experiment shows that hot water will hold more sugar in solution than water at room temperature. If we think in terms of room temperature we say that when we have a solution which contains more sugar than it will normally hold it is *supersaturated*

Temperature is most important in its influence on solubility. If a given solution of sugar in water is undersaturated at 180 degrees Fahr. and exactly saturated at 100 degrees Fahr. it would be supersaturated at 70 degrees Fahr., if it were possible to retain the sugar in solution at this temperature.

Under certain conditions it is possible to have a solution supersaturated. Often with very slow, undisturbed cooling normal crystallization will be retarded. The result is a supersaturated solution. As long as the solution is undisturbed it will remain supersaturated. We then have a condition of *metastable* equilibrium. Metastable conditions are frequently encountered in metals, especially in iron and steel. In many cases (as we shall see later) a metastable condition in metals is the result of abnormally rapid cooling. In liquids it is the result of abnormally slow cooling.

In metastable equilibrium the atoms (or molecules) are held in their position by their rigidity and lack of freedom of movement. If this rigidity is released, even to a slight extent, there frequently is an immediate reversion to a condition of stable equilibrium.

In the case of a supersaturated solution, if the solution is stirred, or if a small crystal of the substance is dropped into the liquid, rapid crystallization will take place until the disturbed equilibrium is restored and the exact degree of saturation for the existing temperature is reached. In the case of metals in metastable equilibrium the application of heat will often cause partial and sometimes complete reversion to a condition of stable equilibrium.

Crystallization of Metals

The mechanism of crystallization of solids from a liquid solution has almost a direct counterpart in the crystallization of metals. Practically all metals crystallize in solidifying. In addition, recrystallization and crystal growth take place in some metals after solidification is complete. We speak of a liquid solution being undersaturated, saturated or supersaturated. We will also speak of a solid solution of two metals or of a metal and nonmetal and will speak of saturation, and supersaturation as it applies to the solid state. We will also discuss equilibrium conditions in metals, particularly iron and steel, while they are in the solid state. When these problems are reached the justification

for the extensive discussion of liquid solutions in the foregoing pages will be apparent.

As we have already stated, practically all metals crystallize in solidifying. A simple experiment illustrating this may be performed with bismuth. Melt some bismuth in a small crucible. Let it cool until the freezing point is reached. When the contents of the crucible are partially solid, pour the still molten metal from the center of the crucible. Beautiful rhombohedric crystals will be seen growing inward from the walls of the crucible.

Iron crystallizes in solidifying. Were conditions such that crystallization would be uninterrupted it would be found that the iron particles formed almost perfect cubes. Osmond obtained these perfect cubes by the reduction of ferrous chloride.[2] Practically, these conditions are never wholly met as crystallization starts at numerous centers and proceeds by deposition of solid particles of iron from the melt until arrested by contact with another crystal mass.

Fig. 1 shows Rosenhain's classic illustration of the mechanism of crystallization in metals. It shows how the solid metal deposits at various centers and proceeds in orderly arrangement along regular geometric planes. Fig. 1 shows crystallization in two dimensions. Actually these regular planes extend in three dimensions.

It is unnecessary to dwell on the many proofs of the crystallization of iron.[3] The small, shiny, crystalline particles evident in a fractured surface of low carbon steel are familiar to every steel worker. Occasionally iron crystals of more-or-less perfect geometrical form are found. Fig. 2 shows such crystals.[4] These large crystals are caused by parallel growth of the gamma iron octahedra and are found most frequently in the pipe cavity of large ingots where the gradual shrinkage of the molten metal has made possible this partial perfection in form. These octahedra belong to the cubic crystal family[5] and are in themselves strong evidence that iron forms cubic crystals on solidifying.

Ordinarily the crystallization of iron is nearly always com-

[2]Sauveur, Metallography of Steel and Cast Iron, 1916, page 104.

[3]See Howe, Metallography of Steel and Cast Iron, 1916, page 269, et seq.

[4]From the frontispiece of Howe, Metallography of Steel and Cast Iron, McGraw-Hill Book Co., 1916.

[5]The octahedron has the same axes, planes and center of symmetry as the cube. Although their forms are different, both crystals are cubic. See Bragg, X-rays and Crystal Structure, Harcourt Brace & Co., 1924, page 79, et seq.

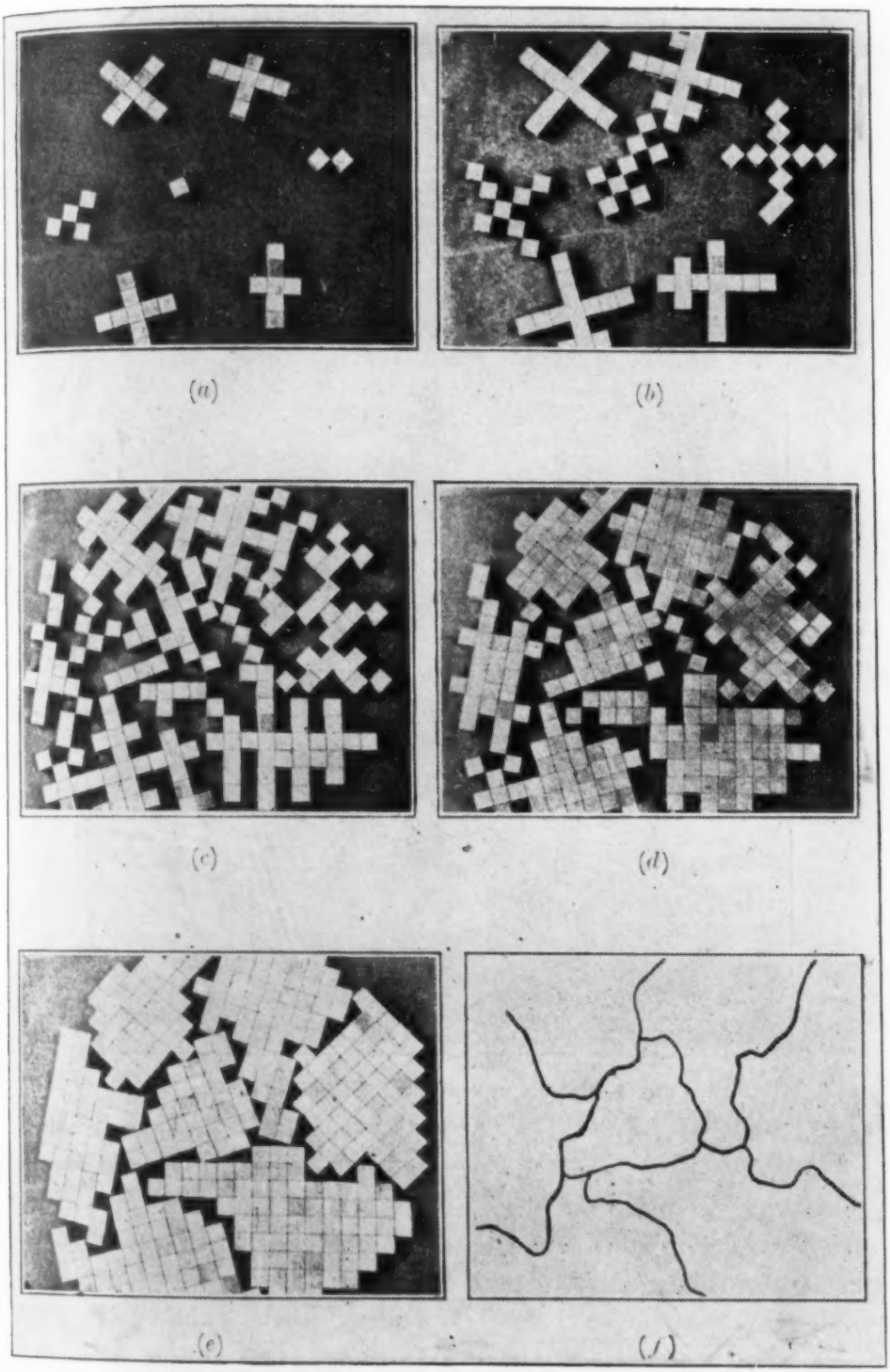


Fig. 1—Illustrating the Growth of Crystalline Grains. (From Dr. Walter Rosenhain's book entitled "Introduction to Physical Metallurgy.")

plete before perfection of form is attained. These imperfect crystals are commonly spoken of as grains (Fig. 1). The appearance and size of these crystalline grains when viewed on a freshly fractured surface is responsible for the steel mill terms, "coarse-

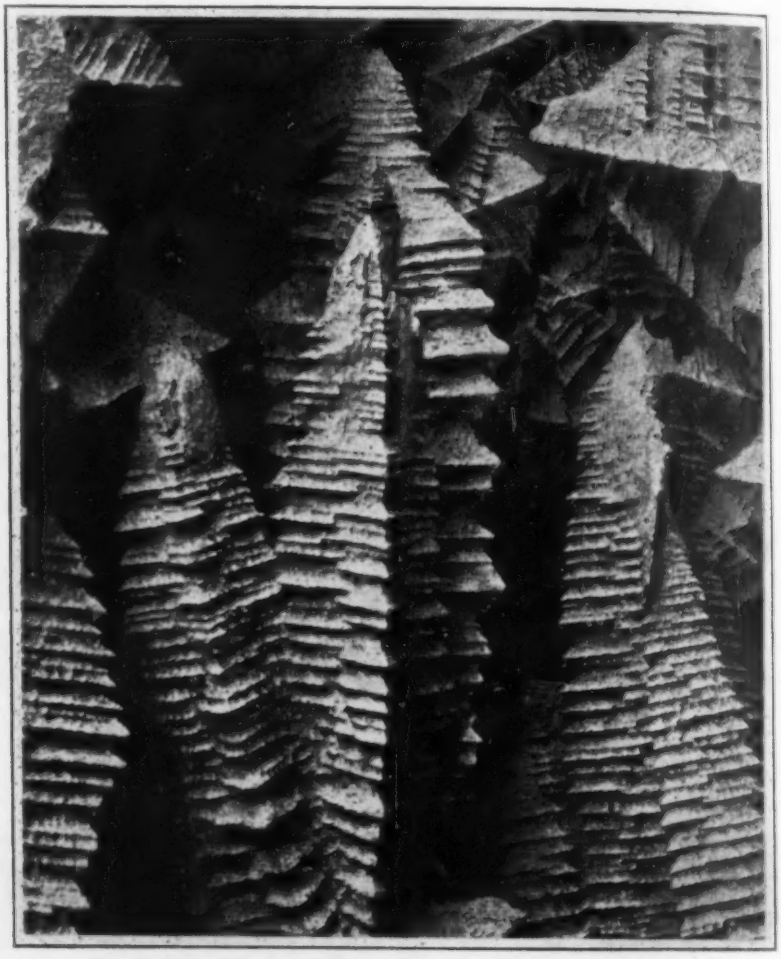


Fig. 2—Crystals of Austenite. Half Natural Size.

grained, fine-grained, shiny, dull, fibrous, silky" and many others.

The appearance of the crystalline grains as viewed by the microscope is shown in Fig. 3. This is a photomicrograph of a very low carbon steel and shows the polyhedral[6] grains of almost pure iron. The relative size of the grains as viewed by the microscope may vary a good deal depending upon whether the plane of polishing intercepted the grains along their major axis or in some other direction. It is possible, however, to gain a fairly ac-

[6]Polyhedral from polyhedron, a closed geometrical solid bounded by plane faces, necessarily four or more.

Fig. 3—Polyhedral Grains in Very Low Carbon Steel. Etched with Alcoholic Nitric Acid. 100x.

curate idea of grain size by the examination of a polished and etched specimen with the microscope.

Orientation and Cleavage

Orientation is an arrangement of the principal crystal planes in the same general direction. All of the crystal units in a single grain are similarly oriented, that is the direction of their principal planes is the same. Fig. 1 illustrates this property. Howe[7] has described orientation so well that his words will be quoted without change.

> "The essence of the crystalline state is first that the molecules group themselves into minute crystal units which may be likened to the bricks of a house or the tiles of a mosaic pavement; and second that these adjoining units lie parallel and in symmetry, or in short that they have identical direction or orientation, as soldiers are arranged in platoons, companies, and regiments. This identity of orientation, of internal geometrical arrangement, extends throughout each of the crystalline grains of which we

[7]Loc. Cit. page 259.

see the polygonal sections in our micrographs, but naturally changes at the boundary line of each grain to a different orientation in each of the adjoining grains. It is to this geometrical arrangement that all the characteristics of the crystalline state are due.''

Cleavage planes are planes of low strength occurring within the crystal unit. These planes have low resistance to shear. Failure practically always occurs by the slipping of the crystal units along these planes of weakness.[8] A proof of the weakness of these cleavage planes is that failure of metals under stress nearly always occurs through the crystalline grains and not along the grain boundaries.

If the cleavage planes of all of the grains were geometrically symmetrical the metal would be relatively weak. As each grain is differently orientated, however, it happens that the cleavage planes are not symmetrical hence although the cleavage plane of the individual grain may not resist deformation strongly, the sum total of all of the grains in the metallic section will resist deformation very well. From this it follows that a fine-grained structure will resist failure better than a coarse-grained one. We will have an opportunity to look at this phase again when we discuss the effect of heat treatment on grain size.

Crystal Structure

The polyhedral grains evident in our photomicrographs (Fig. 3) are made up of crystal units similarly oriented in the same grain but differently oriented in different grains. The atoms (or molecules)[9] making up the crystal structure are grouped according to definite, repeating, geometrical patterns. This pattern is known as a space lattice, and consists of a series of points in space so located that each point is situated similarly to every other point.[10] If we divide the space lattice into unit cells by three sets of parallel planes, the planes of each set will be parallel and equi-distant from each other, but the distance between the planes need not be the same for all three sets. The planes of

[8]This is clearly illustrated in some substances. If a large crystal of Calcite ($CaCO_3$) is struck a sharp blow with a hammer it will break or *cleave* into many fragments, breaking along the cleavage planes. Each small fragment will have the same symmetry as the large piece.

[9]Metals are monatomic, that is the molecules contain only one atom each.

[10]For detailed discussion and description of the space lattice see Report of Sub-committee VI of Committee E 4 on Metallography, on X-ray Metallography. A. S. T. M. Vol. 25, part 1, 1924.

different sets may form any angles with each other. The points where these planes intersect is the space lattice.

Most metals form crystals belonging to the cubic system. There are two modifications of this system:[11] one is known as the body-centered cubic lattice; the other is the face-centered cubic lattice. Fig. 4 shows the theoretical conception of the body-centered cubic lattice. One atom is represented as being at each of the eight corners of the cube and one atom at the exact center. Fig. 5 shows the face-centered cubic lattice. One atom is located at each of the eight corners of the cube and one atom is in the exact center of each of the six plane faces. It should be noted

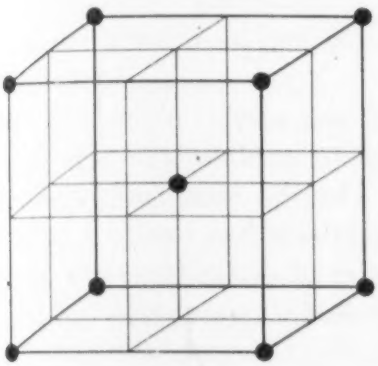


Fig. 4—Body-Centered Cubic Lattice.

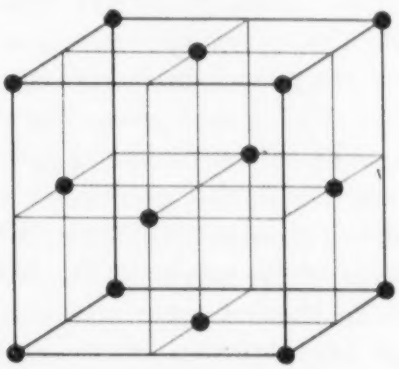


Fig. 5—Face-Centered Cubic Lattice.

that Figs. 4 and 5 are only a geometrical representation of the cubic space lattice, the points represented by the black circles are the theoretical location of the atom centers. The atoms themselves are packed together.

In the body-centered cubic lattice each of the corner atoms in Fig. 4 is shared by seven other cubes or a total of eight cubes to each atom. Hence the body-centered cubic lattice contains the equivalent of one whole corner atom and one whole center atom or a total of two atoms. In the face-centered cube each of the six atoms represented in the center of the six plane faces is shared by one other cube, or a total of two cubes to each face atom. Thus the face-centered cubic lattice has the equivalent of one corner atom and three face atoms or a total of four atoms.

It is assumed that these crystal particles or atoms are held together in this spacing by strongly attractive forces. That these forces are exceedingly strong is evidenced by the regularity of

[11]Actually there are three, but the third, the simple cube is not found in metals.

form assumed by the metal when crystallizing from its melt. It is also assumed that these strong, attractive forces prevent the disintegration or distortion of the regular arrangement of the atoms; in other words, prevent the distortion of the lattice. Evidence of any abnormality in the shape of spacing of the atoms or the space lattice is evidence of abnormality in the structure of the metal. Of course the converse is also true.

Recrystallization in the solid state, as for example the allotropic change from gamma iron (face-centered cubic) to alpha iron (body-centered cubic) involves a change in atom arrangement. The energy necessary to respace the atoms, in overcoming these strong, attractive atomic forces is evidenced by an evolution or absorption of heat which may be measured accurately by means of the proper instruments.

For many years the concept of the space lattice has been merely a convenient hypothesis used to explain the orderliness and regularity of crystal structure. In the past few years evidence obtained by X-ray diffraction methods has removed the picture of the space lattice from the realm of conjecture and placed it in that of certainty. It is now possible to measure the interplaner distances in the space lattice and thus fix with certainty the position of the atoms in the crystal unit. In addition it is possible to determine the weight and volume of the atom with a high degree of accuracy.

By means of the X-ray it has been found that at ordinary temperatures iron crystallizes as a body-centered cube (Fig. 4), gamma iron, the high temperature allotropic modification (which will be discussed later) crystallizes as a face-centered cube (Fig. 5).

Amorphous Solids

As has been discussed in detail above the crystalline state postulates an orderly arrangement of the atoms in the crystal unit and an orderly arrangement of the crystal units in the individual perfect crystal or in the imperfect crystalline grain. Crystalline solids are characterized by a similar orientation of planes in each individual grain and by the presence of cleavage or planes of weakness similarly orientated in the same grain, but differently orientated in different grains.

There is another state which is known as amorphous. In this state the atoms are not orderly, they are spaced haphazardly;

there are no geometric planes. There is no orientation nor cleavage. Amorphous means having no crystalline form. All gases are amorphous, as are most liquids. Practically all molten metals are amorphous. In the solid state the amorphous is much less frequent than the crystalline. There are, however, some well known amorphous solids, one of the most familiar is glass. Even in the case of glass, one of the best examples of amorphous solids, care must be exercised in making glass and it must be cooled quickly to prevent crystallization. From this it follows that in many cases in the amorphous state the atoms (or molecules) are not in equilibrium. We might say that in glass the atoms (or molecules) are in metastable equilibrium. That is, they are fixed in their haphazard position by their atomic (or molecular) rigidity. If, however, the material could be treated—by heat or in some other manner—so that a certain degree of freedom would be given to them, they would tend to establish a stable equilibrium, in this case the crystalline state.

An example of this return from the amorphous to the crystalline state, familiar to all steel chemists, is the crystallization of silica combustion tubes. As received from the manufacturer these tubes are hard, white, vitreous, fused silica, a splendid example of an amorphous solid. After continually heating these tubes, to about 1900 degrees Fahr. over a period of weeks or months, crystallization gradually takes place. A tube with a completely crystallized zone will fracture with a clean break if twisted or bent slightly in the hands. A new tube will withstand a blow of considerable force before breaking, and will shatter irregularly, very much the same as glass. The difference in the appearance of the fracture of the amorphous and crystallized tube is readily apparent.

Amorphous solids are considered by many to be undercooled liquids of high viscosity. If a long glass rod of small diameter is supported by the ends, after a period of weeks it will sag appreciably at the center, indicating that the solid has flowed to a certain extent, much as though it were a liquid of high viscosity.[12]

It has been found that iron in the amorphous state is formed in the interstices between the grains where there is too little

[12]Under certain conditions crystalline aggregates of ductile metals will flow in a similar manner. The creeping of lead illustrates this. The great difference in the time factor leaves no doubt as to the difference between the crystalline and the amorphous. In addition it has been found that it is only crystalline aggregates that flow; the individual crystal will not.

space for the atoms of the molten metal to assume a definite spatial arrangement and take on the orientation of either crystalline grain (Fig. 1). Undercooling may enter importantly here.[13]

In general, amorphous metal is harder than the crystalline, due primarily to the fact that it has no cleavage or slip planes, consequently it resists deformation equally in all directions. The hardness of amorphous iron has been used to explain the strength obtained by cold work. What is thought to be amorphous iron is formed by cold work. This is evident to anyone experienced in polishing specimens for microscopic examination. Unless suitable precautions are taken, a layer of amorphous metal will flow over the specimen being polished. Examination of the polished and unetched specimen will reveal a beautiful, smooth, polished surface. When the specimen is etched this amorphous layer is eaten away and the scratches underneath revealed.

Allotropy

In its broadest meaning allotropy may be defined as the occurrence of an element in two or more different modifications. For example, sulphur may exist in three allotropic forms; one amorphous modification, melting at 248 degrees Fahr. and two crystalline modifications, the monoclinic melting at 247 degrees Fahr. and the rhombic melting at 238 degrees Fahr. The two crystalline forms have very different melting points and belong to entirely different crystal families.

Carbon is another familiar element that may exist in several allotropic forms. It occurs in nature as the hard, crystalline diamond and the soft, flaky, crystalline graphite. In the amorphous form it occurs as coal, charcoal, coke, lamp black, animal charcoal and many others. These three forms of the element carbon although differing markedly in appearance, have many properties in common. This is characteristic of all allotropic modifications of the same element.

Many of the metals are known to exist in more than one form. The tin of commerce is a silvery white crystalline metal. At low temperatures an allotropic change takes place in the metal which gradually disintegrates into a gray crystalline powder. The allotropic change is accompanied by an increase in volume. Dean[14] gives the equilibrium temperature of the change as 68

[13] Beilby was first to suggest the amorphous cement theory. See Howe Loc. Cit. chapter 20.

[14] Theoretical Metallurgy, page 29.

degrees Fahr. The two modifications differ in crystal form and appearance.

In the above examples the general definition of allotropy applies without qualification. The allotropic forms of sulphur, carbon, or tin are readily recognized by their differences in appearance, they are characterized by being either amorphous or crystalline and if two allotropic forms are crystalline they differ widely in their crystal structure.

The Allotropic Forms of Iron

In general the allotropic modifications of such elements as sulphur, carbon and tin are clearly recognized. In the case of iron which exists in two, possibly three or four allotropic crystalline modifications, this is not always the case.

If a sample of pure electrolytic iron is heated to a high temperature, say 2000 degrees Fahr., (1100 degrees Cent.) and allowed to cool slowly, changes will take place in the metal in cooling accompanied by an evolution of heat.

If the furnace is allowed to cool slowly and uniformly and the temperature drop of the iron measured carefully by means of a very accurate thermocouple, an arrest will be noted when the temperature reaches 1650 degrees Fahr. (900 degrees Cent). For a brief interval the temperature of the specimen will remain constant although the furnace is cooling at a uniform rate. After this arrest the temperature drop will be uniform until a temperature of approximately 1415 degrees Fahr. (768 degrees Cent.) is reached where another heat evolution will occur and the temperature of the piece will remain constant although the furnace is cooling uniformly. After this slight arrest the temperature drop will be constant until room temperature is reached. If the temperature is plotted against time a curve similar to that given in Fig. 6 will be obtained.

In addition to the evolution of heat at 1650 degrees Fahr. (900 degrees Cent.) the metal which is normally contracting in cooling suddenly expands. After this temperature is passed contraction again occurs. There is also a decided drop in electrical resistance at that temperature. The greatest change taking place is the recrystallization that occurs.

At 1415 degrees Fahr. (768 degrees Cent.) there are small changes in volume, and electrical conductivity. The most marked

change at this point is that the iron becomes magnetic. Below 1415 degrees Fahr. iron is magnetic; above the temperature it is almost completely non-magnetic. The evolution of heat and other changes taking place at 1650 degrees Fahr. (900 degrees Cent.) and 1415 degrees Fahr. (768 degrees Cent.) are accepted

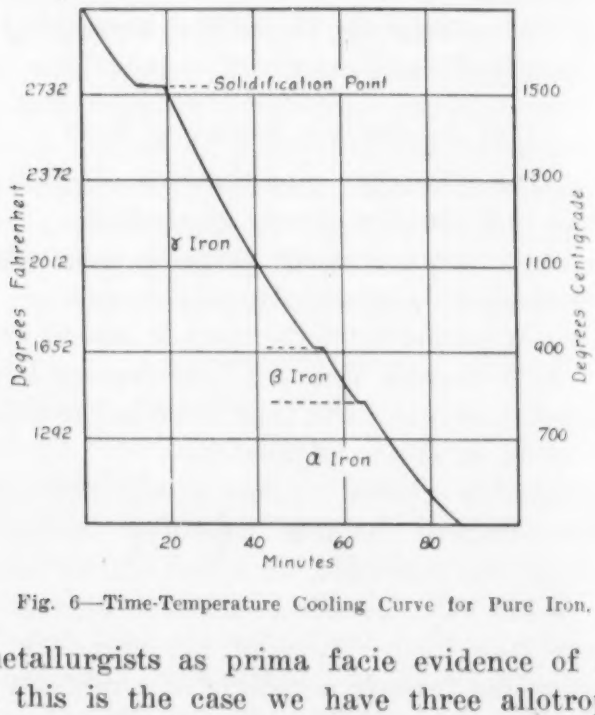


Fig. 6—Time-Temperature Cooling Curve for Pure Iron.

by many metallurgists as prima facie evidence of an allotropic change. If this is the case we have three allotropic forms of iron,[15] gamma, stable above 1650 degrees Fahr. (900 degrees Cent.); beta, stable between 1650 degrees Fahr. and 1415 degrees Fahr.; and alpha stable below 1415 degrees Fahr. (728 degrees Cent.).

X-ray defraction methods have shown that gamma iron stable above 1650 degrees Fahr. (900 degrees Cent.) crystallizes as a face-centered cube (Fig. 5). The recrystallization which occurs at this temperature in cooling, accompanied by an evolution of heat and volume expansion of the metal is the change from a face-centered cubic crystal to a body-centered cube (Fig. 4). At 1415 degrees Fahr. (768 degrees Cent.) there is no change in crystal structure.

If we define allotropy as a change in atomic spacing or as a rearrangement in the atoms then there are only two allotropic

[15]That is, three allotropic crystalline forms. Amorphous iron is an allotropic modification. For the present this may be omitted from the discussion. Delta iron, another allotropic form, is discussed on the next page. Delta iron does not enter into our present conception of the constitution of steel and cast iron hence it is customary to consider only the alpha, beta and gamma forms.

forms of iron (see footnote), gamma iron stable above 1650 degrees Fahr. (900 degrees Cent.) and alpha iron stable below this temperature. With our conception of allotropy based on crystal structure beta iron does not exist.

The argument as to whether or not beta iron exists has waxed hot in physical metallurgy for many years and has never been settled. The X-ray showed definitely that there was no change in atomic spacing at 1415 degrees Fahr. (768 degrees Cent.). The proponents of the beta iron theory have a strong argument in the almost complete gain or loss in magnetism which takes place when the metal is cooled or heated through this point.

An acceptance of beta iron is not necessary to an understanding of the structural changes taking place in steels. It only appears on the iron-carbon diagram for low carbon steels, and the question of its presence is relatively unimportant even here.

In addition to the two transformations occurring at 1415 degrees Fahr. (768 degrees Cent.) and 1650 degrees Fahr. (900 degrees Cent.), a transformation point has been found occurring in iron at 2550 degrees Fahr. (1400 degrees Cent.). The allotropic (?) modification of iron stable above 2550 degrees Fahr. (1400 degrees Cent.) is called delta iron. Westgren found that at this temperature iron changes from a face-centered (gamma) to a body-centered (delta) cube, the same crystalline form as alpha iron. It is now generally accepted that an allotropic change takes place at 2550 degrees Fahr. (1400 degrees Cent.) and that delta iron exists.

Editors' Note:—The second installment of this series will discuss transformation points and their determination, solid solutions and eutectic alloys.

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part VII

By H. B. Knowlton

Abstract

This article discusses several methods of producing a variation in the hardness, strength, toughness, and other physical properties of different portions of the same piece of steel. Differential heating, differential quenching and differential drawing are described. Some illustrations are given of the application of these methods to practical problems. A brief discussion of the effect of the different methods on the gradation zone between the soft and the hard areas, is also given.

Differential Hardening

IN practical heat treating it is often desirable to produce different degrees of hardness, toughness, and other physical properties in different parts of the same piece. Drills, reamers, taps and other shank tools should have hard cutting edges but tough shanks. Hammers and dies should have hard faces but it is desirable for the other portions to be tough. Files have hard teeth but soft tangs. Sometimes it is desired to perform some machining operation (other than grinding) in one portion, after hardening. This obviously makes it necessary for that portion to be soft.

The first duty of the hardener in solving any problem in heat treating is to study the tool or article to be hardened and learn how it must function in service. He should determine the degree of hardness, toughness, strength, etc., which are desirable in different portions. In this connection it is well to make a difference between softness and toughness. Portions which are to be machined must necessarily be as soft as practicable. On the other hand, toughness is often required when softness is not necessary.

[1]The first installment of this series of articles appeared in the March, 1925, issue of Transactions, the second installment appeared in the June, 1925, issue, the third installment appeared in the October, 1925, issue, the fourth installment appeared in the January, 1926, issue, the fifth installment appeared in the April, 1926, issue, and the sixth installment appeared in the May, 1926, issue.

The author, H. B. Knowlton, member of the Milwaukee Chapter of the Society, is instructor in metallurgy, Milwaukee Vocational School, Milwaukee, Wisconsin.

Similarly the heat treater should recognize the difference between hardness and brittleness. While it may be true in the case of pieces which are hardened and tempered correctly, that the ones which are the hardest are also the most brittle, it does not follow that brittleness is always due to excessive hardness or that great hardness must be accompanied by excessive brittleness. The practice of describing a piece which fails due to brittleness, as being "too hard" is misleading. A piece which is overheated prior to quenching for hardening will have a coarse grain and will be brittle. While drawing or tempering may reduce the brittleness, it will not refine the grain. No matter what the drawing temperature, a piece which is overheated in hardening will be more brittle than one which is hardened correctly and drawn to the same temperature.

The production of a variation in the hardness, strength, and toughness, in different portions of the same piece may be accomplished in several ways. These may be grouped into three general classes:—1. differential heating; 2. differential quenching; 3. differential drawing.

Differential Heating

In this method only the part to be hardened is heated above the critical point while the rest is not allowed to become hot enough to harden. Pieces thus heated may be quenched all over as only the portion which is heated above the critical point will become hard. One end of a steel piece may easily be hardened by this method when melted lead or melted salt baths are employed to do the heating. The portion which it is desired to harden is plunged into the melted bath and is held there until it reaches the temperature of the bath. By controlling the temperature of the melted bath with the aid of a pyrometer, it is a simple matter to avoid any danger of overheating. The bath is maintained at the correct hardening temperature, and the piece is removed when it reaches the exact color of the bath. In production work where large numbers of pieces of the same size and design are to be hardened, it is possible to operate this method entirely on a time-temperature basis. Once the time required to bring a tool of a given size to the hardening temperature has been determined, it is sufficient to heat other tools of the same size and design for a similar length of time, providing

of course that the quantity of melted lead or salt and the method of operating the furnace remains the same in every case.

The heating by this method is so rapid that there is not time for much heat to be conducted to the portion of the steel which is above the surface of the melted bath. Unless the time of heating is extremely long, it is safe to assume that only the portion which is immersed in the melted bath will become hard. If the time of heating is too short there may be danger that not all of the portion which is immersed will harden. At the surface of the bath the heating is slower than it is farther down due to the conduction of heat to the portion which is out in the air.

An interesting application of the use of the rapid heating of lead pots in the production of differential hardening, has been reported in connection with the hardening of long staybolt taps. These tools frequently must withstand more or less bending loads in service. Consequently it is desirable to produce the maximum toughness without sacrificing the hardness of the cutting edges. In order to accomplish this the taps were heated in a lead pot barely long enough to bring the outer layer to the hardening temperature, but not long enough to allow the center to reach that temperature. Consequently after quenching, the taps showed a hardened layer at the surface and a soft core or center. By accurate control of the time of heating any desired depth of hardness could be produced.

The method just described is a rather radical departure from the usual practice of lead pot hardening. It is much more common to allow the temperature of the lead to penetrate to the center of the piece being heated, regardless of whether the entire piece or only one end is immersed. For most work it is usually considered better to have the temperature uniform at the time of quenching.

While discussing the advantages of the rapid heating of lead pots, it may not be amiss to give a word of caution. From the standpoint of warping, cracking and distortion, rapid heating is far from desirable. This was discussed in more detail in a previous article.

The heating of one portion of a piece of steel in an oven furnace is not so easy unless the furnace is especially designed for that purpose. When an oven furnace is employed for differential heating, it is necessary to place the steel in the door so

that the end to be hardened projects into the oven. The temperature of the portion of the oven near the door is rarely the same as that of the center or the rear of the furnace. Unless the thermocouple used for measuring the temperature is placed near the steel being heated, it may be doubtful whether the steel has or has not reached the correct temperature. Furthermore heating by this method is much slower than lead pot heating and there is more time for conduction of heat to portions of the steel which are not intended to be hard.

Nevertheless this method has been used practically in production hardening of cold chisels. The furnace employed had a very low roof. The hearth was comparatively wide but not very deep. The hot end of the thermocouple was placed in the same zone as the ends of the chisels being heated. This zone was maintained at the correct temperature for hardening chisels, so there could be no danger of overheating. In this way only the ends of the chisels were heated, so no especial care in quenching was required. As the hearth was quite wide a number of chisels were in the process of heating at the same time. As fast as one chisel was removed and quenched, another was put in the furnace in its place. Thus the operation was kept up continuously.

For years the blacksmiths have used simple forge fires for heating one end of a tool. The end to be hardened is placed in the center of the fire, which is of course the hottest zone. The temperature is necessarily estimated by eye. While it is possible to do good hardening by this method, there is danger of overheating, particularly if the temperature of the fire is higher than the correct hardening temperature. If the tool is thin near the cutting edge it is very easy to overheat the edge.

More recently the acetylene torch has been used in local hardening. This method produces very rapid heating, due to the very high temperature of the oxyacetylene flame, consequently it is possible to heat a small area to the hardening temperature before a great deal of heat is conducted to the rest of the tool. Again the temperature must be estimated entirely by eye, and as the temperature of the flame is very high and the heating very rapid, it is easy to make the mistake of overheating, particularly of thin sections. The method involves all the dangers which accompany rapid local heating.

Differential Quenching

It is possible to produce a variation in the hardness, strength, and toughness of different portions of the same tool, by cooling the various portions at different speeds. This may be termed "differential quenching." When this method is employed, either the entire tool or only the part which is to be hardened, may be heated to the hardening temperature. Differential quenching may be accomplished in several ways.

Partial Quenching

The end of the tool which is to be hardened may be quenched in water while the remainder is allowed to cool in air until it is below the critical point on cooling, after which the whole tool may be quenched. (The critical point on cooling for ordinary plain carbon tool steel is a dull red heat. It is a good safe rule to allow the part of the tool which is to be soft to cool until black before quenching). This produces the maximum hardness in the part quenched first while the remainder is given an air cooled structure, which for plain carbon steel is nearly as soft and tough as annealed steel. It does not produce the maximum strength and stiffness in the part which is cooled in air.

If, in the operation of this method, tools of considerable size are held by tongs while quenching, a great deal of the hardener's time is consumed waiting for parts cooling in air to become black. However, in many cases, it is possible to design racks which will hold the tools at the proper depth in the quenching tank. It is probably best for the hardener first to quench the part which is to be hard until it is reasonably cold, following the usual rule of keeping the piece moving during quenching so that it continually comes in contact with cold water. The tool may then be stood in the rack while the unquenched portion is cooling down.

Bullens advises moving the tools up and down slightly during partial quenching to avoid producing a line of demarcation between the hard and the soft zones. He attributes the failure of drills in service to the fact that they were held still during quenching. This will be discussed more fully later.

Drawing or tempering is sometimes combined with the partial quenching method. For example, the blacksmith usually hardens a cold chisel by plunging the cutting edge of the chisel about one-half inch under the surface of the water. When the cutting

edge is cold, he removes the chisel from the quenching tank and quickly polishes the scale off the portion which was quenched. The heat remaining in the shank conducts down toward the cutting edge thus producing the tempering action. During this operation a band containing all the temper colors from straw to blue may be seen to move down the polished surface toward the cutting edge. When the desired temper color reaches the cutting edge, that end of the chisel is again quenched to prevent further heating and tempering. If the shank of the tool is black the whole chisel may be quenched. The time of the drawing operation and the width of the band of temper colors depends on the amount of heat left in the shank. It is frequently true, however, that only a very narrow zone at the cutting edge is given the desired temper color. The zone next above this is drawn to a higher temperature and consequently is somewhat softer and tougher.

While this method may give satisfactory results on cold chisels and similar tools which have a cutting edge at the end only, it is not recommended for tools such as taps which have cutting edges over a considerable length of the tool. It would be difficult, if not impossible, by this method to produce the same temper color on the entire cutting portion of a tap.

In any event, color drawing cannot be recommended as an ideal method of tempering. It requires too much of the hardener's attention and is open to too many errors. This was discussed more fully in a previous article.

Quenching one part in water and the remainder in oil

Another type of differential quenching consists in heating the entire tool to the hardening temperature, followed by quenching one end in water until nearly cold and then quenching the remainder in oil. This method may be applied to plain carbon steels and to other steels which acquire maximum hardness by water quenching, but only a moderate amount of hardness by oil quenching. Obviously, it is not applicable to steels which attain maximum hardness on oil quenching or air cooling, as the portion quenched in oil would not be any softer or tougher than that quenched in water. When hardening in this manner it is necessary to withdraw the tool from the water and quench it in

oil while there is still enough heat in the upper part of the tool to produce some hardening action.

This method is recommended for many shank tools such as drills, reamers, taps, etc. It has the advantage of hardening the cutting portion of the tool and at the same time producing a strong, tough shank. When the tools are hardened in this manner, the shanks will have a great torsional strength, that is, they will resist more twisting forces, than would be possible if the shanks were allowed to cool in air until black while the cutting portions were being quenched. At the same time, shanks which are quenched in oil are not as brittle as those quenched in water.

This method must necessarily be followed by tempering or drawing to the proper temperature. This is usually accomplished by heating the entire tool in oil, in a bath of some low melting salt, or in a special drawing furnace. If necessary, it is possible to draw the shank further than the cutting edges by thrusting the shank into melted lead or some melted salt maintained at the desired temperature. This will be discussed later.

Retarded Quenching

It is also possible to produce differential quenching by retarding or slowing down the quenching of the portion which requires less hardness or more toughness. This may be accomplished by surrounding that portion with fire clay or similar material before heating. Clay heats slower and cools slower than steel. Consequently, a greater length of time is required to heat the entire tool to a uniform temperature. When the tool is quenched, the portions which are not covered with clay cool fast and become hard, while the portions beneath the clay cool much slower and consequently do not become so hard. Of course, the amount of the retardation of the cooling will depend upon the thickness of the clay covering. If the clay is thick enough, the steel beneath will come out quite soft after quenching.

This method is particularly advantageous in the production of soft areas in the central portions of the tools or other articles. It is common practice to fill small holes with clay or some similar material before hardening. This prevents the sudden cooling inside the holes and thus avoids much of the danger of cracking. For similar reasons screw threads and other sharp internal angles which do not need to be hard, are frequently filled with clay.

The use of clay has a practical disadvantage in that clay tends to shrink and crack off during heating. This may be largely overcome by proper mixing of the clay. In the first place it pays to use a good grade of fire clay. Secondly, it is well to avoid making the clay too wet. When applied the clay should be barely wet enough to stick together. Lastly, certain other materials mixed with the clay will aid in avoiding cracking. Some have found that asbestos fiber in the proper proportions will help hold the clay together. A mixture of clay and sand works very well in filling holes. When heated sand expands and clay shrinks. Water glass mixed with clay when heated forms a hard, firm coating. The objection to this mixture is the difficulty of removing the coating after quenching. While it may be removed quite easily from smooth external surfaces it is not always so easily removed from screw threads and holes. There are a number of especially prepared mixtures on the market which are said to adhere during heating and quenching, but which may be easily removed afterwards. It should be remarked that all of these materials may also be used to advantage in preventing carburizing of certain areas during case hardening.

When the clay completely surrounds one portion of the article to be hardened, it is sometimes practicable to re-enforce the clay with a ring made of iron or steel pipe. This may be quickly applied and removed, and it prevents the clay from coming off.

One objection to the use of clay is the time and labor required in mixing and applying it. This is counterbalanced to some extent by the saving in labor in quenching as it is not necessary to hold the piece in the tongs while waiting for the part beneath the clay to cool. If the quenching tank is provided with a screen, it is possible to drop the piece on the screen as soon as the exposed portions are cold.

Articles which are hardened by the method just described should be drawn all over in oil or some suitable type of drawing furnace.

Differential Drawing

A variation in the hardness, toughness and other properties of different portions of a steel article may also be produced by drawing the various portions to different temperatures. Such differential drawing or tempering may be accomplished in several ways.

The method of drawing cold chisels by the heat left in the shank after partial quenching, has already been described. The same principle is sometimes used in the drawing of drills, screw drivers, hammers, large die blocks, and other tools which are hardened by partial quenching. In every case the drawing temperature is judged by the temper color produced. While this method has the advantage of drawing other portions further than the working edge or face, it is very much doubted if it can be recommended as the best treatment for any of the tools mentioned.

Sometimes die blocks are completely cooled down in hardening and are drawn by being placed with the back down on a hot plate. In this way the heat is applied to the back and conducts up through the block to the face. If the heating is fast enough it is possible to draw the back and the center of the block to higher temperatures than the face, thus producing the required hardness on the face and at the same time toughening the rest of the block to a greater degree than could be accomplished by drawing the entire block to a uniform temperature. This method may be applied to blocks that are either partially or totally quenched. The tempering temperature is usually judged by the color of the face. Sometimes hardness tests are made during tempering. In any event, the block must be removed and cooled rapidly when the proper color or hardness of the face is reached, to prevent further tempering.

A cruder scheme, which is the same in principle, consists in placing the block after hardening in the door of the heating furnace with the back toward the oven. This method is not so easy to control. Its principal advantage lies in the fact that it requires no extra equipment for drawing.

While speaking of the hardening and tempering of die blocks, it should be stated that the methods just briefly described are applied to carbon tool steel blocks, rather than to the newer air and oil hardening alloy steel blocks.

Die blocks have been mentioned as one example of differential drawing with the help of a hot plate. The same principles may be applied to other tools.

Milling cutters, hammers, and other tools containing holes which should be tough, are sometimes drawn by placing a hot arbor in the hole. This draws the hole further than the rest of the tool. This may be logical from a theoretical consideration.

but the method is open to many practical objections. It is doubtful if this method can be recommended.

When one end of a tool is desired to be quite soft, it is sometimes advisable to harden the whole tool and draw that end by immersing it in melted lead, salt petre or some other melted salt, maintained at a dull red heat. The rapid heating by immersion in a melted bath will soften the end without greatly affecting the rest of the piece. Softening or toughening of one portion to a lesser degree may be accomplished in the same manner if the lead or salt pot is run at a lower temperature. Obviously this method is not practicable when it is desired to produce a soft portion in the middle of the tool.

Blow torches and gas flames have sometimes been used in differential drawing. While in skillful hands this method may yield satisfactory results, it is doubtful if it can be recommended. It may well be asked whether this method does not lead to cracking and distortion.

Gradation Zone Between Soft and Hard Areas

In producing a variation of physical properties in different portions of the same piece, it is best to avoid producing a line of demarcation between the soft and the hard areas. It is preferable to have a zone in which the hardness increases gradually. It may be interesting in this connection to note the effect of some of the treatments described on the width of the gradation zone between the soft and the hard areas.

In order to illustrate these effects, four small pieces cut from a thin flat bar of plain carbon tool steel were treated in the following manner:

Bar No. 1. Heated all over to 1400 degrees Fahr. and quenched half way in water. The upper half of the bar was allowed to cool in air. The bar was not moved up and down during quenching.

Bar No. 2. One-half heated to 1400 degrees Fahr. by immersion in melted lead; quenched all over in water.

Bar No. 3. One-half covered with clay; heated in an oven furnace to 1400 degrees Fahr. and quenched all over in water.

Bar No. 4. Entire bar heated to 1400 degrees Fahr. and quenched all over in water. One-half drawn by immersion in melted

lead. The other half remained in the air and was drawn only by the heat conducted up the bar.

After these treatments each bar was tested with a Rockwell machine using the diamond cone penetrator. Readings were taken $\frac{1}{32}''$ apart. The results are tabulated below.

ROCKWELL HARDNESS READINGS

Diamond Cone Penetrator Intervals $\frac{1}{32}''$.

Bar 1 Heated all over Quenched half way.	Bar 2 Heated half way, Quenched all over	Bar 3 One half covered with clay. Heated and quenched all over.	Bar 4 Heated and quenched all over. Drawn by immersing one half in lead.	
68	68	66	67	62
68	69	67	68	61.5
68	69	66	66	60.5
67	69	56	66	59.5
65	62	50	65	60
62	53	49	64.5	59.5
55	35	48	64	59
45	32		63.5	57
42	32		63.5	56.5
	31		63	57
			63	57
			62	55.5
Minimum readings in softer portion				
32	30	40		
			Minimum	53

CONCLUSIONS

It will be noted that Bar No. 1 showed a drop in the hardness reading of 22 points in $\frac{1}{8}$ inch, Bar No. 2—27 points in $\frac{1}{16}$ inch, Bar No. 3—16 points in $\frac{1}{16}$ inch, Bar No. 4—10 points in $\frac{5}{8}$ inch. This would indicate that the partial heating method produces decidedly the most abrupt change in the hardness. This seems quite logical as the part of the bar which was heated to temperatures below the critical point should not harden at all.

The bar which was heated all over but quenched half-way showed a more gradual change in hardness. This was probably due to the fact that the part of the bar which was just above the surface of the water during quenching was cooled fairly rapidly by conduction of the heat toward the end which was immersed. This is confirmed by practical experience in partial quenching.

Some hardening effect is usually noted above the water line. Consequently when it is desired to produce one end quite soft, it is not advisable to quench quite up to the spot which should be soft.

It may be noted with interest that the piece protected with clay showed a fairly abrupt change. There was, however, some hardening effect apparent beneath the clay. The results produced on this particular bar might not always be duplicated when this method is employed. The thickness of the clay coating and the time of heating might have considerable influence upon the results.

Bar No. 4 which received the differential drawing treatment showed the most gradual change in hardness. This might naturally be expected.

Summary

A variation in the physical properties of the same piece of steel may be produced by differential heating, differential quenching or differential tempering. Differential heating is easily accomplished by bath heating. This method of heating is rapid and the temperature can be accurately controlled. While it is usually more difficult to produce differential heating in an oven furnace, it can be accomplished if the furnace is properly designed. The forge fire and the oxyacetylene flame involve the risk of personal errors.

Differential quenching may be accomplished by (1) quenching one part in water or oil and cooling the remainder in air; (2) quenching one part in water and the remainder in oil; (3) retarding the cooling of one portion by clay or some similar coating.

Differential tempering is produced by heating one portion higher than the rest during tempering. This gives the most gradual change in the hardness. When the degree of tempering is judged by temper colors the method is open to errors.

All of these methods may give good results if properly carried out. It is the duty of the heat treater to study the articles to be hardened, learn how they are to function in service, and determine which method is the most suitable for producing the desired results.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

THE HARDNESS OF CARBON STEELS AT HIGH TEMPERATURES By I. G. Slater and T. H. Turner. *British Iron and Steel Institute*, May 1926.

The authors are of the opinion that if riveting takes place between 800 and 1200 degrees Cent. that steels of higher carbon content up to the eutectoid composition will be harder to drive.

A distinct advantage is to be gained by using higher temperatures at least so far as the energy required in shaping the rivet is concerned, if the danger of burning can be eliminated. They state that a medium carbon steel rivet will be as soft at 1100 degrees Cent. as a wrought iron rivet is at 900 degrees Cent.

So far as the practical value of these results is concerned, it is of importance that work, such as cutting off fins, done below 800 degrees Cent. will in all cases require an expenditure of greater energy than would the same operation carried out with the metal above this temperature, especially in steels of higher carbon content.

In the process of riveting by hammering a cooling rivet, the authors are of the opinion that, with hammer blows of equal force, the first impact will produce more of the desired shaping than will any one of the subsequent blows, and the number of rivets driven per hour will depend more upon the speed with which the first blow is struck than upon the total physical energy expended.

STUDY OF THE STRESSES IN SOFT IRON BY THE METHOD OF TEMPERING. By S. P. Vologdine, *Journal* of Russian Metallurgical Society, 1925, I, 67.

Specimens of boiler iron plates were subjected to tension, compression and torsion up to destruction; then they were cut to separate pieces and were subjected to tempering at the temperatures of 650, 750 and 830 degrees Cent. for 4, 8 and 12 hours. After this the average size of the grains in all the pieces was measured microscopically, and thus were found the portions where the recrystallization after tempering was more sharply defined. As it was possible to calculate beforehand for every such portion the stresses, to which the metal was subjected under cold treating, there could be found the connection between the degree of cold treating and the average size of grain after tempering. It was found by the author that critical stresses of 74,000, 41,000 and 36,500 pounds per square inch, under which the metal became coarse-grained after tempering, corresponded to temperatures of 650, 750 and 830 degrees Cent. By subjecting specimens of iron boiler plates to recrystallization by tempering at the given temperatures and by measuring the size of grains afterward, the author obtains a figure as to the size and distribution of stresses,

to which the metal was subjected at temperatures of drawing not sufficiently high, and consequently about the degree of cold working of the different portions of the metal.

Abstracted by M. Oknoff and G. N. Koulginski, Leningrad, Russia.

AIR FURNACE HAS UNDERFEED STOKER. By Burnham Finney. In *Iron Age*, April 22, 1926, page 1119.

New design of annealing ovens, temperature regulating equipment and annealing cycle chart are installed and have proven successful in the new foundry of the Berryhill Malleable Iron Company, Evansville, Ind.

The underfeed stoker in the melting furnace is practically a new operation in malleable foundry practice. The stoker automatically feeds the furnace with coal by means of rams operated by air cylinders which are actuated by Cole automatic valves. The writer describes the air furnaces and says they differ from the ordinary hand-fired furnaces inasmuch as they require no top blast.

The annealing ovens have unusual flue construction and have pyrometer control. Their operation cycles are recorded on charts.

The molding department has no partitions, hence sand cutting is facilitated.

The many illustrations add to the value of the paper.

ON THE VOLUME CHANGE DURING SOLIDIFICATION IN CAST IRON AND PURE IRON. By Kotarô Honda and Hikozo Endo.

With the object of confirming the view, that in the iron-carbon system, graphite formed during solidification is a decomposition product of cementite, but not the product of a direct precipitation from the melt, the present writers measured the change of volume of different cast iron during solidification which contained nearly the same amount of carbon, and different amounts of silicon. The method of experiments is based on the change of buoyancy undergone by the sample which was placed in a vessel made of refractory material and dipped into melted sodium chloride; during the cooling through its solidification range, the change of buoyancy was observed by means of a thermobalance, and thus the volume change was calculated. The results of observation are as follows:

Specimen	Total Carbon Per Cent	Graphite Carb. Per Cent	Silicon Per Cent	Observed $\left(\frac{\delta v}{v}\right)$ Per Cent	Calculated $\left(\frac{\delta v}{v}\right)$ Per Cent
1	4.3	3.08	2.03	1.65	1.66
2	4.2	3.06	2.31	1.63	1.64
3	4.2	2.80	1.28	1.18	1.18
4	4.1	2.20	0.44	0.47	0.16
5	4.1	2.06	0.38	0.00	—0.18
6	4.0	1.17	0.08	—1.76	—1.55

As the graphite carbon decreases, observed $\frac{\delta v}{v}$ changes from a positive value to a negative. From the $\frac{\delta v}{v}$ graphite curve, the volume change in the case of no graphitization can be estimated to be –3.6 per cent. On the other

hand, if we admit that the graphite present in these cast irons is a decomposition product of cementite, we can calculate the volume change due to the decomposition of cementite from the quantity of graphite present in the cast irons, and hence the actual change of volume can be obtained by the relation:

$$\frac{\delta v}{v} = -3.6 + \left(\frac{\delta v}{v}\right) \text{ decomp. } (\%)$$

The values given in the last column of the above table are the volume changes calculated by the above relation. The coincidence between the calculated and observed values are very satisfactory, showing the correctness of the view referred to in the beginning. *Abstracted by Dr. Kotaro Honda.*

PROGRESS SHOWN. By Dan M. Avery. In *The Foundry*, April 15, 1926, page 314.

The author reviews the great improvement made in foundry construction, equipment and character of product during the past twenty-five years and is of the opinion that steel and malleable castings rank high. The cupola is still supreme with few exceptions.

The marked change in foundries from 1900 to 1926 might indeed be termed revolutionary,—so tremendously has it developed. The type of building has been improved and made not only more attractive but more adapted for its uses.

The inadequate lighting of the interior of the shop often resulted in poor work and in discomfort to the workers and frequent accidents were directly attributable to insufficient lighting.

The electric crane was a novelty. In those days hand or hydraulic power was used. Now electricity lifts and carries the burdens.

The machinery in 1900 was crude and of very limited capacity and endurance.

The quality of production has been much improved largely through research work and the development in metallurgy. Scientific advancement made in practically every branch of the foundry industry has resulted in greater tonnage and finer product. Perhaps the greatest strides in foundry practice during this quarter century have been in mechanical equipment.

The author sets forth in a table the total pig iron and foundry iron produced from 1900 to 1925 and by a graph shows the heavy gains in steel castings production made during this period of time. He also tabulates the total number of foundries in the United States and Canada operating during this time.

AVOID EMBRITTLEMENT IN MALLEABLE IRON CASTINGS. By Edwin Bremer. In *Iron Trade Review*, April 15, 1926, page 993.

A new process of heat treatment and quenching removes galvanizing difficulties and aids machining. The loss of product is reduced materially. This heat treating process was used for over 8000 tons of castings with only slight loss due to embrittlement.

The author shows by photographs the castings moving slowly through the rotating furnaces where they meet a gradually increasing temperature. The furnaces are oil-fired and the temperatures are checked by pyrometers. A

continuous quenching chamber assists in making the process automatic. He also shows an oil-fired muffle furnace which heat treats castings of intricate form that might be damaged in the rotating furnaces.

ON THE ABRASION OF CARBON STEELS. By Masuhiro Susuki. In *Kinzoku no Kenko* No. 3, 1926, page 149.

The writer measured the coefficients of abrasion of different kinds of hypo-eutectoid carbon steel. Both the standard and relative coefficients of abrasion were observed; the former is defined as the amount of abrasion W_{sn} of a given substance A with respect to the standard substance N per unit work and the latter as that of abrasion W_{ab} of a substance A with respect to any other substance B. The method of experiments consists of measuring the amount of wear taking place in the contact surfaces of an annular shape of two vertical cylindrical tubes revolving about a common vertical axis under a given load; the frictional force acting between these two contact surfaces became constant after a certain interval of time, which value was recorded on a cylinder and taken in the calculation of the work done. The results are as follows:

1. Under a given coefficient of friction, the amount of abrasion of a steel is proportional to the applied work.
2. The coefficient of abrasion of a given steel increases rapidly as the coefficient of friction increases.
3. Under a given coefficient of friction between two abraiding steels A and B, the amount of wear in steel A increases linearly with the carbon content of steel B. On the other hand, the amount of wear in steel B with respect to steel A decreases rapidly as the carbon content of steel B increases.
4. Between the standard and relative coefficients of abrasion, a following simple relation approximately holds good:

$$W_{ab} = K \frac{W_{bn}}{W_{an}}$$

where K is a function of the coefficient of friction.

In the present case $\mu = 0.65$ and $K = 7.8$, the unit of work being kilogram-meter and that of wear miligram. *Abstracted by Dr. Kotaro Honda.*

THE PRESENT STATUS OF RESEARCH OF METALS. By F. Körber, Düsseldorf. *Zeitschrift des Vereines Deutscher Ingenieure*, April 10, 1926, pages 494 to 496.

In this paper the author describes the fundamental points of view of modern scientific investigation in metals.

The first disclosure on structure was given by the examination of metallic fractures. A great progress in the knowledge of the internal texture of metals was made by the introduction of the microscopic. The arrangement of the crystallites to each other and their size are intensively influenced by the solidification conditions. The number of nuclei and the velocity of crystallization is dependent upon the temperature, and the conditions of the flow of heat are determinant on the crystallization. By the aid of the X-ray method of

examination it is possible to gain an even deeper insight into the internal structure of metals than by the microscopic examination. The great importance of the constitution diagrams is mentioned. The structure given after solidification is subjected in numerous cases to further changes. Some metals have polymorphous transformations at certain temperatures. The structural changes of alloys in the solid state are of particular importance; in addition to the transformations, possible in the constituents of an alloy, there are still other possible structural changes owing to separation phenomena. The explanation of the constitution of alloys by the aid of constitution-diagrams has given the impetus to a systematic investigation of the physical properties of the alloys in dependence on the chemical composition and it has been evident that in alloys which are composed of two sorts of crystals, the properties change linearly with the composition but that in homogeneous mixed crystal series the change takes place in a catenary-curve. Metallic materials are distinguished by the fact, that they show great changes of properties in the range of remaining deformations at sufficiently low temperatures, especially in mechanical properties. By annealing at higher temperatures the original properties recur; the material recrystallizes. The investigation of the mechanism of over-elastic deformation on single crystals is briefly described and it is shown, that the space-lattice structure of a metal is not lost even at great deformation. The investigation of over-elastic deformations of metals is of great importance, because it may give the elements of the mechanism of plastic deformation. In testing metallic materials the properties of the metal are ascertained almost without exception in the state of great plastic deformation. *Abstracted by Dr. Hans Pollack.*

MAKING HIGH GRADE STEEL—X. By J. A. Coyle. In *Iron Trade Review*, April 22, 1926, page 1057.

The author is of the opinion that plow makers as well as steel manufacturers share the responsibility for ultimate results and that the pitfalls in production and fabrication are numerous.

The writer enumerates the variety of causes for complaint, rejection and replacement which illustrate the difficulties encountered in the production and marketing of soft center plow steel.

By means of illustrations he sets forth the internal breaks in ingots of steel that was not properly made; the sheared shapes used in plow making; a specimen of 3-ply soft center plow steel with one corner battered to show character of inner and outer layers and a few assembled plows, indicating the variety of shapes required. A table showing the use of scrap for soft center plow steel is given.

HEAT-TREATMENT DATA ON QUALITY STEEL CASTINGS. By A. E. White. In *Mechanical Engineering*, May 1926, page 497.

The author sets forth his findings on the heat treatment of quality steel castings. The chemical composition for straight carbon steel castings is given and the proper conditions surrounding the casting of the metal are enumerated but the paper is mainly concerned with a discussion of the influence of heat treatment on the physical characteristics of steel castings.

The results of the laboratory tests on dendritic and non-dendritic steels

in the untreated, annealed, normalized and drawn, and spheroidized condition are tabulated as are also the heat treatments on the impact value of steel castings.

Laboratory tests were augmented by plant tests and the results are given.

When the standard of test is high strength, fair ductility, and maximum resistance to impact, the normalizing and drawing treatment will be found to be the best, is the conclusion of the author.

ELECTRIC MELTING FURNACES IN THE METAL INDUSTRY. By Oberingenieur Th. Metzger, Eberswalde. *Zeitschrift des Vereines Deutscher Ingenieure*, March 13, 1926, page 349 to 356.

Among the great number of electric furnaces for melting non-ferrous metals, only the induction furnace and the rotating or oscillating electric arc-radiation furnace have proved their special availableness; for melting alloys, especially difficult of fusion, the high frequency furnace enters in competition.

The means employed in electric furnaces to mix well the molten metal to obtain a uniform alloy are: mechanical, as turning or rocking the furnace; electrodynamical, as the pinch-repulsion-motor-effect and streaming of the metal owing to the differences of the specific gravities, depending on different temperatures.

The author describes detailed different types of electric furnaces: The Roechling-Rodenhauser furnace, the Ajax-Wyatt furnace as examples of induction furnaces; as examples of electric arc furnaces; the Booth furnace, the Rheinmetall furnace, designed by the author, and the Detroit rocking furnace of the Detroit Electric Furnace Company, Detroit.

The Rheinmetall furnace possesses a rotating drum and is constructed to be immediately connected on polyphase electric current. The electrodes, entering by one front side and displaced against each other at an angle of 120 degrees, meet under a certain angle to the horizontal line inside the furnace. The drum may be changed within one or two hours without disconnecting other parts of the furnace. The charging door and the tap hole are placed on the front side opposite the electrodes. The refractory furnace lining consists of basic chamot, withstanding 300-600 heats. The furnace is constructed with capacities of 225 to 450 pounds (100-200 kilograms), 1100 to 1650 pounds (500-750 kilograms) with a current-consumption of 250 kilowatts and cos =0, 9-0, 8, and 2200 to 2400 pounds (1000-1200 kilograms) with a current-consumption of 350-370 kilowatts and cos =0, 9-0, 8; the working voltage amounts 90, 100 or 110 volts.

The preferences of the rotating electric-arc furnaces are:

1. Good fitness of mixing,
2. Good utilization of heat, and connected with that small
3. Power-consumption.
4. Small waste of metal and the possibility to be able to begin the next heat without the aid of a molten charge.
5. Independence from the electrical conductivity of the fusion.
6. Independence in the choice and the succession of the alloys to be melted.

Further the high frequency furnace, type Ajax-Northrop, is described.

Finally the author gives the general preferences of electric furnaces, which are:

1. Simple regulation of temperature,
2. Small loss of metal,
3. Omission of gas or fuel, in purifying the charge.
4. Omission of the crucible-costs,
5. Good mixing of the fusion,
6. Greater homogeneity of the metal,
7. Lower wages,
8. More healthy conditions for the workmen.

Abstracted by Dr. Hans Pollack.

STUDIES ON CHILL CASTINGS. By Kojiro Homma. *Kinzoku no Kenku* 3, (1926), No. 2, pages 96-117.

The author investigated different factors affecting the hardness of chill casting. The results of experiments with an iron mold are as follows: (1) The rise of the maximum temperature of the melt increases chill effect; but the pouring temperature does not affect it; (2) the increase of heating interval affects the chill in the same way as the rise of the maximum temperature, but in a less degree; (3) the effect of the maximum temperature and that of heating interval are due to the diminution of dissolved gases in the melt; (4) carbon content increase the chill effect; (5) silicon content above 1 per cent decreases the effect; (6) the temperature of the iron mold up to 550 degrees Cent. does not much affect the chill; (7) the effect increases with the thickness of the mold; (8) the composition of the material, the maximum temperature and the thickness of the mold are three important factors affecting the chill hardness.

Abstracted by Dr. Kotaro Honda.

THE EFFECTS OF ARSENIC ON STEEL. By Alan E. Cameron, M. Sc. and G. B. Waterhouse, B. Met., Ph. D. *British Iron and Steel Institute*, May meeting.

In discussing this subject the authors are of the opinion that although the effects of arsenic are in many ways similar to those of phosphorus they are not evident until the amount of arsenic present greatly exceeds the maximum allowable amount of phosphorus. They point out the effect of arsenic on the physical properties of steel and found in their investigation that during forging the arsenic-bearing steels all seamed badly showing that arsenic tends to induce red-shortness. Their reaction to heat treatment was the same as steel without arsenic.

In the mechanical tests arsenic showed a tendency to increase the tensile strength with an increase in hardness and a decrease in ductility. It also has an apparent effect on the shock-absorbing property of the metal.

The authors describe the results of their investigation and by means of tables set forth the analyses for arsenic segregation; chemical analyses of forged metal; comparison of results of determinations for arsenic; transformation points of arsenic steels; results of mechanical tests of arsenical steel and the corrosion of arsenic steel.

Longitudinal and cross sectional microscopic specimens etched with

various acids and reagents are shown in the 21 photomicrographs included in the paper. A bibliography is attached.

SELECTING THE PROPER STEEL FOR MAKING SHOP TOOLS. By J. B. Mudge. In *Iron Trade Review*, April 29, 1926, page 1117.

In answer to the question "What is the best steel for making tools," the author states that it is doubtful if there is a "best," but is of the opinion that for all around purposes high speed steel seems to meet the requirements. General specifications are meaningless, in his opinion, but those which give reasonable manufacturing variations and tolerances,—specifications which tell the manufacturer what is wanted are helpful. "The use of a uniform base from a known source is good insurance when selecting tool steels," says the writer. He further sets forth the various tests applied to detect defects in the raw material and claims that the microscopic test is probably best for evaluating the condition of the steel.

He also considers the human element and automatic temperature control of great importance in the hardening of steel.

In discussing non-shrinking steels the writer "wishes to point out that there is no such thing as non-distorting steels."

The results and observations of 13 different blanking tools operated through 113 setups over a period of 18 months are set forth.

CENTRIFUGAL PIPE FROM SAND MOLDS. By W. D. Moore. In *Iron Age*, April 15, 1926, page 1055.

This article tells how the "Sand-Spun" or "Mono-Cast" product is made in a new plant and contains details covering the molds, sand, and finished product.

The raw materials consist of the ordinary grades of pig iron available in the Birmingham district and standard by-product coke is the melting medium; modern cupola practice is used in converting the iron to the fluid state.

The author continues with a description of the refractory molds and the casting of the pipe. He also explains the cooling oven and the cleaning of the pipe and the tempering and regenerating of the sand. He next describes the handling of the hot metal.

A description of the new plant together with a floor plan is given.

THE THEORY OF STEEL HARDENING. By B. D. Enlund. Värmländska Bergsmannaföreningens Annaler 1925, page 8 (meeting in Karlstad, Sweden, April 25, 1925).

Summary of observations made by the author (comp. Journal of the Iron and Steel Institute 1925, I, p. 305) and by others, in regard to changes in microstructure, hardness, specific volume, electric resistance and latent heat accompanying the austenite-martensite transformation during quenching and the subsequent transformations in austenite and martensite that take place, gradually or abruptly, during tempering to increasing temperatures.

The hardness of hardened steel is due partly to the enforced solution of iron carbide in alpha iron, partly to cold-working resulting from the expansion occurring when austenite transforms into martensite. By varying the rate of cooling, for a suitable steel, martensite of different hardness could

be obtained. A silicon manganese steel of 0.30 per cent carbon, after cooling in water, oil and air gave a Brinell number of 488,450 and 277 respectively, in each case showing martensitic structure. Faster cooling lowers the temperature of transformation and hastens the transformation process, thus a greater amount of cold-working and increased hardness being the result.

On tempering hardened steel, residual austenite—always present—passes into troostite, always via the martensitic stage. The delay in softening or even increase of hardness in the tempering range at 210-270 degrees Cent. is due to the formation of fresh martensite and consequent cold-working.

During the subsequent discussion the occurrence of a martensitic stage in the tempering of austenite was questioned. Further, the belief was expressed that in the air-cooled specimen mentioned, of Brinell hardness 277, considerable amounts of secondary ferrite were present.

Abstracted by Axel Hultgren.

ON THE THEORY OF HARDENING OF METALS. By Kotaro Honda, *Kinzoku no Kenku* 3, 1926, No. 1, page 1-12.

The author distinguishes two kinds of hardness: (1) natural hardness of each individual crystals constituting metals, (2) the change of hardness as affected by external conditions or the state of aggregation of micro-crystals. The natural hardness is to be explained by the law of atomic force. The increase of hardness by cold working, by fineness of grains or by inter-strain belong to the second kind. The author explains these increases of hardness, as well as, the phenomena of blue shortness, and the temper hardening in quenched steels and cold-worked metals. The general belief that the distorsion of the space lattice causes the hardening of the metals, is shown mathematically to be incorrect. Hence the increase of hardness in a continuous solid solution consisting of two components is explained by means of grain size; this new explanation was also confirmed by an experiment.

Abstracted by Dr. Kotaro Honda.

INFLUENCE OF CASTING-TEMPERATURE AND OF ANNEALING ON THE SIZE AND FORMATION OF THE PHOSPHIDE-EUTECTIC. By Dr.-Ing. H. Jungbluth and Dipl.-Ing. H. Gummert. *Kruppsche Monatshefte,* March 1926, pages 41 to 46.

It is known, that the phosphide-eutectic is netlike if cast iron is hot poured and equally distributed, if the iron is cold-poured.

The changes of the phosphide area, of its grain size and of its microscopic form at different casting temperature was investigated. For this purpose a series of heats of different chemical composition was made in a crucible melting furnace and of every heat two ingots were poured—one hot, the other cold. The microscopic examination of the ingots showed that the amount of phosphide-eutectic was smaller in the hot-poured tests than in the cold-poured. The grain-size and the formation was the same in both cases. To investigate the influence of annealing, the ingots were divided in parts, which were annealed at 930, 1110, 1525 and 1650 degrees Fahr. (500, 600, 830 and 900 degrees Cent.) for two hours. About 1525 degrees Fahr. and even better about 1650 degrees Fahr., there was a conglomeration of the phosphide-eutectic and a diffusion of phosphorus in the ferrite, so that the quantity of phosphide-eutectic decreased.

Abstracted by Dr. Hans Pollack.

Reviews of Recent Patents

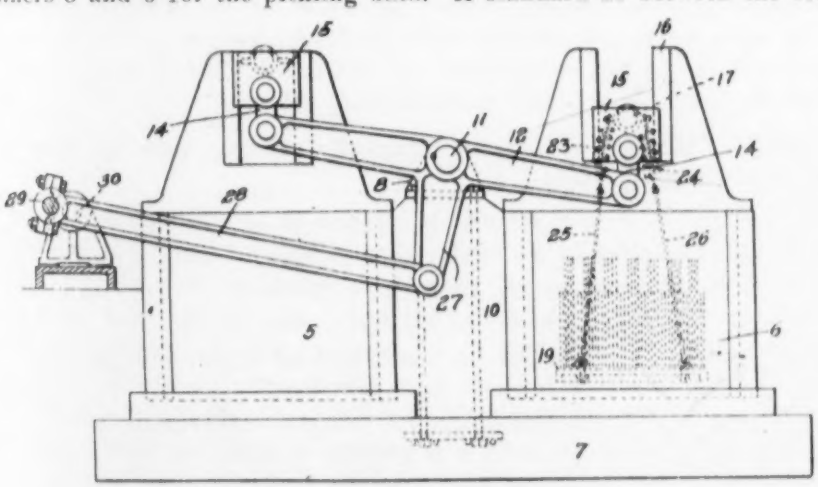
By
NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City
Member of A. S. S. T.

1,573,937, **Method of Producing Cast Iron, John Clifton Henderson, of** of New York, N. Y., Assignor to Driver-Harris Company, of Harrison, New Jersey, a corporation of New Jersey.

This patent describes a method of producing cast iron containing small portions of nickel and chromium which increase the wearing properties and tensile strength of the iron. It is the object of the inventor to overcome the difficulties heretofore met with in the introduction of nickel or chromium into the cast iron because of the high melting point of the nickel and the tendency of the chromium to oxidize and slag off from the iron bath. In carrying out his method, the inventor forms an alloy of nickel-chromium and iron containing approximately 60 per cent nickel, 12 per cent chromium, 27 per cent iron and 1 per cent carbon. Due to the presence of the relatively large amount of iron, the alloy has a melting temperature of approximately 2200 degrees Fahr., and is introduced into the cast iron mixture in the form of shot or small pieces by placing the alloy in the bottom of the ladle and pouring a molten iron, which has been heated to approximately 2500 to 2700 degrees Fahr. over the nickel-chromium alloy. In view of the high nickel and chromium content of the alloy, relatively small proportions are needed to produce in the final alloy the nickel and chromium content desired. Thus from one to two pounds of the alloy, mixed with one hundred pounds of molten iron produces a final product having nickel 0.45 to 2.40 per cent., chromium 0.09 to 0.48 per cent., carbon 3.25 to 4.25 per cent. and iron 95.37 to 91.95 per cent.

1,573,977, **Pickling Machine, Leif Lee, of Youngstown, Ohio.**

This patent describes a pickling machine comprising a base 7 supporting containers 5 and 6 for the pickling bath. A standard 10 between the contain-



ers 5 and 6 supports an oscillating walking beam 12 on the bearings 8 and at each end of the beam 12 over the pickling bath is a vertical reciprocating cross head 15 slidable on the guides 16 positioned above the containers 5 and 6. The sheets, plates or other materials to be pickled are placed on a tray 19, suspended from a rod 17 extending between the slides 15 and are lowered or raised in the pickling solution by oscillation of the beam 12 through the bell crank 27, link 28 and pitman 29. When the trays 19 are in the pickling baths 5 and 6, they are alternately raised a few inches and lowered by oscillation of the walking beam 12 to agitate the articles on the trays to promote uniform action of the pickling liquid.

1,574,131, Method of Making Steel, Iron and Other Metal Plates, Samuel T. G. Smith, of St. Louis, Missouri.

This patent describes a means for preventing sheets or plates from sticking together during rolling or when piled upon one another for heat treatment or other purpose, by placing powdered barytes on the surface of the sheets. Barytes may be applied to the hot sheets and it does not produce any injurious effect upon the sheets, but prevents adhesion of the plates.

1,574,374, 1,574,375, 1,574,376, 1,574,377, Process for Treating Iron, W. J. Diedrichs and Anson Hayes, of Ames, Iowa.

These patents describe a method of heat treating white cast iron to produce a condition, duplicating the properties of commercial malleable iron in a shorter time than is ordinarily required to malleableize white iron. In its principle features, the process consists in raising the temperatures of the white iron castings, either rapidly or slowly, to a point between the critical temperature of the material, 1365 degrees Fahr. and the point of incipient fusion and holding the castings at this temperature from fifteen minutes to five hours, depending upon the temperature chosen and the composition of the iron. The material is then cooled, either rapidly or slowly, to the neighborhood of critical temperature, and this heating and cooling operation repeated any desired number of times, the number of repetitions of these steps depending upon the properties desired in the final product. The final cooling is carried out extremely slowly. The product formed is similar to the commercial malleable iron, having a tensile strength of 44,000 to 53,000 pounds per square inch and an elongation of 15 per cent or more in two inches. The process is considerably shorter than the ordinary malleableizing process.

1,574,550, Method of Making Magnetic Alloys, Vere B. Browne, of Brackenridge, Pennsylvania.

This patent describes a commercial process of producing silicon iron, (for use as a magnetic alloy in an electrical apparatus) having an extremely low carbon content, in large quantities and at relatively low cost. Heretofore, the production of silicon iron alloys having a carbon content of not over 0.03 per cent have been possible only on a laboratory scale. The present invention consists of refining the iron in an open hearth or in an electric arc furnace to remove as much carbon as possible by standard methods, tapping the bath into a ladle and adding sufficient ferro-silicon to raise the heat of the metal to maintain a correct temperature during the Bessemer blow and then trans-

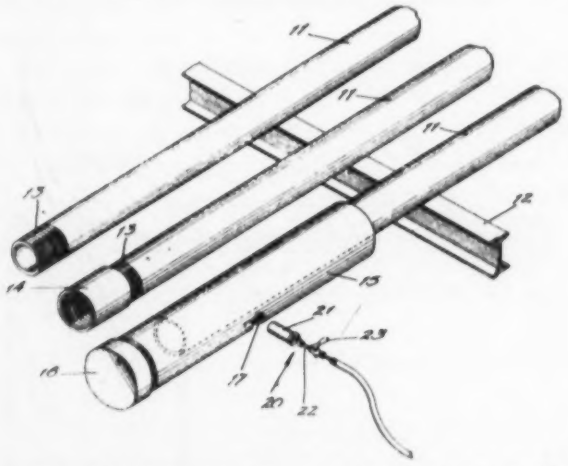
ferring the metal from the ladle to a Bessemer converter and overblowing to remove substantially all traces of carbon and then adding the desired amount of silicon to the carbon free iron. A great deal of the silicon is removed in the converter and the proper amount of low carbon ferro-silicon is added in the ladle following the Bessemer blow.

1,574,782, **Nonmagnetic Steel, Erich Becker, of Kladno, Czechoslovakia, Assignor to Poldihutte, of Praha-Vinohrady, Czechoslovakia, a Joint Stock Company.**

This inventor has discovered that nickel-manganese steels containing six to fifteen per cent. of manganese, seventeen to four per cent. of nickel and up to ten per cent. of chromium possess a high drawing limit while still preserving the general properties of nickel-manganese steel. The chromium content may be replaced by molybdenum or vanadium, or by both of these metals. The metal is substanially nonmagnetic.

1,575,087, **Apparatus for Annealing Pipe, Charles W. Bardeen, of Long Beach, California, Assignor to B and B Pipe Shops, Inc., of Long Beach, California, a Corporation of California.**

This patent describes a field method for heat treating or annealing a drill pipe for use in drilling oil wells and other purposes to overcome the defect of crystallization of the pipe. In the drawing, 11 indicates the drill pipes

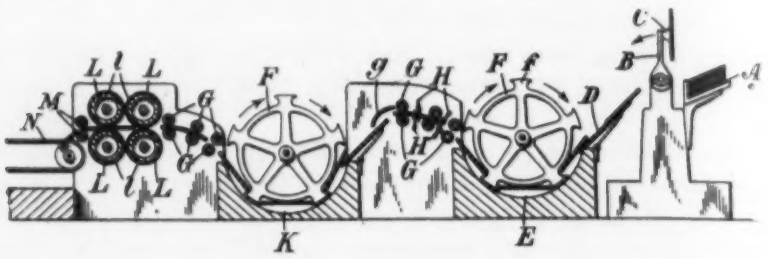


which, through repeated impacts, become fatigued 12 indicates the support for the pipes, 15 is a closed hood for surrounding the end of the pipe to permit the proper concentration of heat, 20 is a gas burner provided with a suitable control cock 23 and mixing nozzle 21 for heating the interior of the muffle 15 by projecting the flame through the hole 17 of the pipe. By using this method the pipe is heated to its highest temperature near the end, the heat being gradually decreased toward the center of the pipe so that there is no sudden change between the annealed and unannealed portion.

1,576,274, **Manufacture of Tin Plate, Gavin Mure Harris, of Lancashire, England.**

This patent claims the process and apparatus for the manufacture of tin plates which comprises passing the plates from the stack A by means of the sucker C through the pickling bath E, thence past the washing sprays H, where

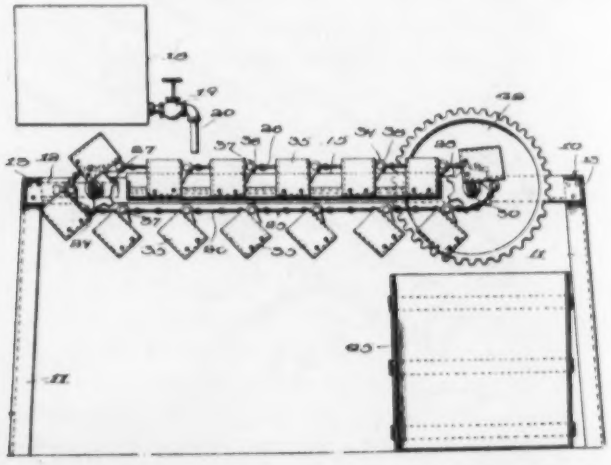
they are swilled to remove acid, through rubber feed rolls G into the water bath K through another series of rubber feed rolls G to the driving rolls L and thence to the conveyor N. The plates are fed through the vats E and K



by means of the rotating wheels F which are regulated to provide the proper pickling period.

1,579,866, Apparatus for Tempering Tools and the Like, Ernest Ellery Jacobs and Marsh Karnes, of West Frankfort, Illinois.

This patent describes an apparatus for tempering cutting bits and other small tools which comprises a tray 15 supported by suitable standards 11 through which a tempered solution, such as oil, water or the like, is circulated from the tank 18. Rotatably mounted adjacent the tray 15 is a chain con-



veyor 26 carrying a plurality of buckets 35 having holes 36 adjacent the bottom thereof through which the oil in the pan 15 may circulate. As the buckets 35 are moved on the conveyor 36, the tools to be tempered are placed therein adjacent the end 12 of the stand and the buckets are moved through the pan 15 in which the tempering solution is circulated through the holes 36 of the buckets. At the end 13 of the stand the bits or cutting tools are dumped into the vat 45 which contains a liquid holding the proper temper on the points of the bits.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

QUESTION NO. 189. *What is the McQuaid-Ehn test and what are its merits in selecting steel for carburizing?*

QUESTION NO. 188. *What causes the scaling on the inside of holes of piston pins when heated in a Hoskins electric pusher type furnace? Does the sulphur content of the steel have any marked effect?*

QUESTION NO. 187. *What causes the carbonaceous deposit on steel parts when quenched in oil from temperatures about 1600 degrees Fahr.? How can this be eliminated? Do all oils have the same effect in the same degree?*

QUESTION NO. 186. *Why should marking dies be rubbed with emery cloth before using?*

QUESTION NO. 185. *What precaution should be observed in designing such a tool?*

QUESTION NO. 184. *What precaution should be observed in quenching tool steels containing chromium?*

QUESTION NO. 183. *What effect, if any, have the additions of alloys on the internal stress of tool steels?*

QUESTION NO. 182. *What indication, if any, is given in the quenching of tool steel if the steel is quenched while going through the critical range?*

QUESTION NO. 181. *How may a pyrometer be checked by means of carbon tool steel?*

QUESTION NO. 180. *Explain the effect of decarburization in grinding.*

QUESTION NO. 179 *What is the difference between grinding cracks and grinding checks?*

QUESTION NO. 175. *How long should high speed steel tools be left in the high draw?*

ANSWER. By E. P. Geary, metallurgical department, Colonial Steel Company, Monaca, Pennsylvania.

It is general practice to reheat hardened high speed steel tools to about 1100 degrees Fahr. and hold for one hour after the tools have been heated uniformly throughout. Experiments show that redrawing and holding for another hour, and also single drawn holding for two hours, does not have any lowering effect on the hardness. The longer draw appears to give the tools a higher degree of toughness than the short draw. The time held in the drawing operation is only necessary to change the so-called austenitic structure, obtained in the steel from the hardening operation, entirely into martensitic structure. This operation gives a harder metal (secondary hardness) and also removes all internal strains set up in the quenching operation.

QUESTION NO. 174. *How long should high speed steels stay in the preheat?*

ANSWER. By E. P. Geary, metallurgical department, Colonial Steel Co., Monaca, Pennsylvania.

High speed steel should not remain in the preheat any longer than necessary to heat uniformly throughout and should then be immediately transferred to the high heat furnace. The time required for this depends on the size of the piece of steel or tool that is to be hardened. The reason for this is to prevent heavy scale and decarburization being formed on the surface of the tool. If it is necessary, in the case of quantity production, to preheat a great number of tools, it is advisable to make use of three furnaces, keeping the large quantity in a furnace with a temperature of not over 1200 degrees Fahr. using an excess of gas for holding at this temperature to prevent oxidation, as high speed steel will not scale at or below this temperature. When ready these tools can be brought up to the regular preheat temperature of 1500 to 1600 degrees Fahr. At the same time, the other preheat furnace can be charged and held at 1200 degrees Fahr. so as to save time in preheating and thereby increase the daily production.

QUESTION NO. 173. *To what temperature must high speed tools be permitted to cool before drawing and why?*

ANSWER. By E. P. Geary, metallurgical department, Colonial Steel Company, Monaca, Pennsylvania.

When quenching high speed tools to harden, they should be allowed to cool to a temperature of 150 to 200 degrees Fahr. before being reheated to draw. The structure being formed in hardening high speed steel will not be complete or "set" until the above range is reached. Quenching or cooling high speed steel from the high temperature range to about 700 or 800 degrees Fahr. and reheating to 1100 degrees Fahr. and holding for any period of time and then cooling or quenching does not produce a hardened and drawn product. Instead you only have a hardened, undrawn piece of steel, as the only effect the reheating had was to retard or delay the original hardening action which wasn't complete until a temperature of about 175 degrees Fahr. was reached.

QUESTION NO. 172. *Can you quench and draw high speed steel in one heating operation?*

ANSWER. By E. P. Geary, metallurgical department, Colonial Steel Company, Monaca, Pennsylvania.

High speed steel should not be quenched and drawn in one operation as a high speed tool should be hardened all over. For instance, high speed shanks, as on reamers and end mills which receive a great deal of strain, should not be left soft, because the hardened structure is the strongest. To harden properly it is necessary to cool the entire tool down to 175 degrees Fahr. and then reheat to draw.

It is possible to use the hardened tool without reheating to draw by allowing the frictional heat generated by use to draw the temper, but the existing quenching strains are liable to crack or cause the tool to break before they are relieved.

QUESTION NO. 171. *What is the hardness of carbon steels at elevated temperatures such as 400 to 1000 degrees?*

QUESTION NO. 170. *Why do you get a low Rockwell reading on Stellite?*

QUESTION NO. 169. *What is the hardness of high speed steel at elevated temperatures such as 400 to 1000 degrees?*

QUESTION NO. 168. *Why is a high draw beneficial to high speed steel?*

ANSWER. By E. P. Geary, metallurgical department, Colonial Steel Company, Monaca, Pennsylvania.

A high draw is beneficial as it allows secondary hardness to take place. High speed steel quenched from the usual high temperature retains the characteristic austenitic structure. In drawing after quenching, the hardness practically remains unchanged until a temperature of about 925 degrees Fahr. is obtained at which point the hardness increases reaching a maximum at about 1092 to 1135 degrees Fahr. The hardness of the steel drawn within this range will often Rockwell two or three points higher than the readings obtained on the undrawn steel. At temperatures above this range the hardness rapidly decreases until a minimum is reached at the annealing temperature on slow cooling. The high draw transforms the austenite into martensite and also relieves brittleness, which together with the increased or secondary hardness are the two most important beneficial reasons for the high draw.

QUESTION NO. 165. *What importance should be placed on the carbon content of high speed steel?*

QUESTION NO. 163. *What is the lowest temperature at which ingot iron or low carbon steel will carburize when packed with the usual type of commercial carburizer?*

ANSWER. By C. G. Williams, mechanical engineer, Barber-Colman Co., Rockford, Illinois.

The temperature at which any steel will carburize depends on the carbon content of the steel. The higher the carbon content, the higher the temperature required to take up carbon from surrounding carburizing materials.

It is believed that ingot steel is generally held to a carbon content of about 0.02 per cent and concerning steels or irons with this low carbon content, the writer cannot state from actual test, but with steels with a carbon content of from 0.05 to 0.12 per cent and from 0.20 to 0.25 per cent and from 0.75 to 0.90 per cent tests have been made to determine the lowest heat at which any appreciable carburizing will take place.

Generally speaking, steels with a carbon content of 0.05 to 0.12 per cent may be classed under low carbon steels, and in the tests made, no appreciable degree of carburizing took place below a temperature of 1519 degrees Fahr., although with one sample of 0.12 per cent carbon, a slight carburizing was detected after 15 hours of heating.

As the carbon content becomes higher, so also does the temperature required to effect carburization. It has been definitely proven that with a carbon content at or above the eutectoid point, the temperature required to effect carburization will be only those above the Ar_2 point of the steel in question.

The following quotations may help to clear up the subject:

SAUVEUR—"The Metallography and Heat Treatment of Iron and Steel," page 315. "While it has been claimed that iron below its critical

point will absorb some carbon, this absorption, if taking place at all, is very slow.''

GIOLITTI—''Cementation of Iron and Steel.'' Claims a carburization in 0.05 per cent carbon steel at a temperature of 1413 degrees Fahr., also of a 0.59 per cent carbon steel at 1533 degrees Fahr. and of a 0.89 per cent carbon steel at a temperature of 1728 degrees Fahr. He also states: ''The authors consider it as proved that the diffusion of carbon occurs only at temperatures above the Ar_2 point of the metal.''

JEFFRIES AND ARCHER—''The Science of Metals,'' page 370, states: ''Low carbon steel heated above about 1290 degrees Fahr. in constant contact with certain carbon containing materials will absorb carbon at the surface.''

BRADLEY STOUGHTON—''The Metallurgy of Iron and Steel.'' ''The cementation process takes place with extreme slowness below the critical temperature of the steel, and increases rapidly with the temperature above that point.'' In a table he shows no penetration at a temperature of 1290 degrees Fahr.

QUESTION NO. 159. *What is the explanation for the retarding effect on corrosion of small amounts of copper in low carbon steel?*

QUESTION NO. 158. *What is the present recognized cause for the ''transverse fissure'' as occasionally found in rails?*

QUESTION NO. 157. *Does 0.070 to 0.090 per cent phosphorus in low carbon basic open hearth steel tend to prevent ''stickers'' in the rolling of sheets? If so, what is the explanation for such a tendency?*

DO YOU KNOW?

1. *What is the weight per cubic inch of metallic nickel?*
   ANSWER: A. S. S. T. Handbook, page C-3.
2. *What heat treatment will place S. A. E. Steel 3450 in a machinable condition?*
   ANSWER: A. S. S. T. Handbook, page C-17.
3. *If stainless steel is tempered at 900 degrees Fahr., what physical properties may be expected?*
   ANSWER: A. S. S. T. Handbook, page D-7.
4. *What carbon and vanadium contents are suitable for locomotive castings, such as frames, wheel centers, etc.?*
   ANSWER: A. S. S. T. Handbook, Page F-8.
5. *How should high speed steel be cooled from the annealing temperature?*
   ANSWER: A. S. S. T. Handbook, pages M-3 and M-4.
6. *If high manganese is used in carburizing steels, what carbon content is suitable?*
   ANSWER: A. S. S. T. Handbook, page R-4.
7. *What is the principle of the thermoelectric pyrometer?*
   ANSWER: A. S. S. T. Handbook, page S-4.
8. *What precautions should be exercised in the preparation of metallographic specimens?*
   ANSWER: A. S. S. T. Handbook, page T-4.
9. *When checking a scleroscope, what attention should be given the hammer diamond?*
   ANSWER: A. S. S. T. Handbook, page V-8.
10. *What type tensile test specimen should be used for brass or copper?*
    ANSWER: A. S. S. T. Handbook, page V-18.

News of the Chapters

STANDING OF THE CHAPTERS

IN the May issue of TRANSACTIONS appeared the relative membership standing of the 28 chapters of the Society as of March 1, 1926, and as of April 1, 1926. The tabulation which appears below shows the relative membership standing of the chapters on April 1, 1926, and May 1, 1926.

Standing of the chapters as of May 1, 1926

GROUP I	GROUP II	GROUP III
1. Detroit (384)	1. Lehigh Valley (133)	1. Tri City (64)
2. Cleveland 375	2. Hartford 132	2. Los Angeles 64
3. Philadelphia 353	3. Golden Gate 132	3. Rockford 59
4. Pittsburgh 321	4. Syracuse 100	4. New Haven 58
5. Chicago 306	5. Milwaukee 100	5. Washington 58
6. New York 251	6. Cincinnati 80	6. Worcester 57
7. Boston 236	7. St. Louis 75	7. Rochester 51
	8. Indianapolis 75	8. Schenectady 49
	9. Buffalo 56	9. Toronto 45
	10. North West 50	10. Providence 43
		11. Springfield 30
		12. Fort Wayne 26

Standing as of April 1, 1926

GROUP I	GROUP II	GROUP III
1. Detroit (383)	1. Hartford (132)	1. Tri City (64)
2. Cleveland (367)	2. Golden Gate (128)	2. Los Angeles (64)
3. Philadelphia (354)	3. Lehigh Valley (117)	3. New Haven (58)
4. Pittsburgh (314)	4. Syracuse (99)	4. Washington (57)
5. Chicago (303)	5. Milwaukee (94)	5. Worcester (56)
6. New York (245)	6. Cincinnati (77)	6. Schenectady (50)
7. Boston (230)	7. St. Louis (72)	7. Rochester (49)
	8. Indianapolis (70)	8. Rockford (47)
	9. Buffalo	9. Toronto
	10. North-West	10. Providence
		11. Springfield

There are in the Society at the present time 3925 members and it is possible that the A. S. S. T. will go over the 4000 mark by the next report. There were 151 new applications and reinstatements this month, while 21 were dropped for non-payment of dues and 13 were lost for other reasons, leaving a net gain of 121 members.

GROUP 1.—Cleveland with 8 new members had the largest gain, while New York and Boston were second, with 6 each.

GROUP 2—Greetings to a new leader in Group 2! Lehigh Valley with a net gain of 16 members last month jumped from third to first place with a lead of 1 member over Hartford, which has held the leadership in this group for a long time. Golden Gate with a gain of 4 is now tied with Hartford for 2nd place, with 132 members each. Syracuse with a gain of 1 and Milwaukee with a gain of 6 have joined the "100 club" and are tied for 4th place. The first 8 chapters in group 2 all showed gains in membership.

GROUP 3—Tri City and Los Angeles are still 1 and 2, with 64 members each as on the last report. However, there is a newcomer in Group No. 3. Rockford, with a gain of 12 members for the month, leaped from 8th place to third, passing New Haven, Washington, Worcester and Rochester. It would be well for Nos. 1 and 2 to look to their laurels, for Rockford is not through jumping yet. Neither Lehigh Valley nor Rockford, the two chapters that have produced remarkable results this month, have on a membership campaign. They are selecting their new members with care, even refusing some applications, not desiring to enroll those whom they feel would not be permanent members of the chapter.

All of the chapters will welcome to Group 3—Fort Wayne—Starting out with 26 members. Fort Wayne will have more members as the applications are now in the office and as it is now undergoing the organization period. Fort Wayne replaces the loss of South Bend.

Next month Montreal will have made sufficient headway to be classified in the groups.

BOSTON CHAPTER

THE annual meeting of the Boston Chapter was held at the Massachusetts Institute of Technology on Friday, May 7, 1926, the following officers being elected at the conclusion of an informal dinner served to seventy-five members of the Chapter in the Walker Memorial:

Chairman—F. H. Cole, metallurgist, Walworth Company

Vice-Chairman—L. D. Hawkridge, vice-president, Hawkridge Brothers Company

Secretary-Treasurer—H. E. Handy, metallurgist, Saco-Lowell Shops

Chairman Program—H. B. Parker, metallurgist, Trimont Manufacturing Company

Chairman Membership—A. Hartel, Jr., president, Hartel Brothers Company

Chairman Reception—C. L. Stott, heat treating foreman, General Electric Company

Chairman Attendance—E. H. Fernald, chemist, Saco-Lowell Shops

Chairman Educational—V. O. Homerberg, instructor of metallography, Massachusetts Institute of Technology

Chairman Employment—J. M. Darke, chief of testing laboratory, General Electric Company

Member at Large of Executive Committee—A. M. Remington, consulting engineer, Simonds Saw & Steel Company

Member at Large of Executive Committee—H. H. Harris, president, General Alloys Company

As has been his custom on several occasions this year, Prof. George B. Waterhouse gave one of his after dinner talks on new things in metallurgy. At this meeting, his subject was in connection with his recent trip to Germany and was entitled "Surface Hardening with Nitrogen." A complete synopsis of this talk will appear in these columns next month.

The principal speaker of the evening was L. Dwight Granger, metallurgical engineer of the Wickwire Spencer Steel Company, at Worcester, who presented a paper on "The Manufacture of Wire Springs." Mr. Granger dwelt at some length on the design of wire springs and called attention to many of the difficulties with which the spring maker is confronted when trying to manufacture springs to some of their customer's specifications. He called attention to the importance of the modulus of elasticity in the design and manufacture of springs and to the fact that while the leading authorities show the value of the modulus in torsion to be 12,600,000, the spring maker finds this value to vary from 9,500,000 to 11,000,000 in actual practice.

Speaking of material used in the manufacture of springs, he stated that there are two kinds of wire in general use, hard-drawn and oil-tempered. Hard-drawn wire, variously called by such names as XL-, gamma and premier, is of the general composition of carbon 0.50 to 0.60 per cent; manganese 0.90 to 1.20 per cent; sulphur and phosphorus under 0.05 per cent; no other alloys being present. This wire has its physical properties by virtue of drawing. The proper size rod is selected, heat treated by "patenting" to secure uniformity, and then drawn to finish size with or without additional heat treatment according to the size to be finished. "Patenting" is rather a meaningless term metallurgically as it simply means that the wire is heated above its critical temperature and then quenched slowly either in air or in a bath of lead, heated to a temperature of from 700 to 1000 degrees Fahr., to insure the proper microstructure. The process was once covered by a patent and hence its name. The structure obtained by "patenting" is mainly sorbitic.

Music wire is another type of hard-drawn wire and the treatment is much the same as for gamma or premier wire, except that the carbon being from 0.80 to 0.90 per cent, the heat treatments are much more delicate and and difficult. The distinctive "piano wire finish" is secured by drawing the wire wet from a tub filled with sour rye meal liquor after coating it with a contact deposit of tin and copper. The tensile strength of gamma or premier wire will run from 160,000 to 220,000 pounds per square inch and music wire from 250,000 to 500,000 in the smaller sizes. The elastic limit of both will be about 55 per cent of the tensile strength.

Oil-tempered wire is usually a 0.55 to 0.65 per cent carbon grade. It is "patented" for drawing much the same as hard-drawn wire and when drawn to the size desired is hardened and tempered continuously. The wire is placed on reels back of the furnace and is pulled consecutively through the furnace, which is 18 to 30 feet long, and heated above the critical temperature of the wire; then through an oil bath kept vigorously circulating and at the proper temperature; and finally, through a lead bath heated to from 800 to 1000

degrees Fahr., according to the spring temper desired in the wire. The tensile strength of oil-tempered wire will run from 200,000 to 300,000 pounds per square inch, but the elastic limit is about 75 per cent of the tensile strength, so that a greater proportion of the ultimate strength can be used in spring design.

One of the most interesting features brought out by Mr. Granger was his description of the treatment given springs after coiling. The coiling of a spring, of course, sets up uneven strains in the wire. It has been found that by "blueing" the springs at a temperature of from 500 to 600 degrees Fahr., this strain is relieved, the metal is stiffened and the spring is not so liable to set. Several questions were answered by Mr. Granger, after which he was given a rising vote of thanks for a pleasant "spring" evening.

Following the meeting, an exhibition of the Eaton-Globar Electric Furnace was given under the direction of I. N. Zavarine, instructor of heat treating at Technology, assisted by members of the Eaton Furnace Company organization. The furnace was brought up to a heat of 2300 degrees Fahr. in about forty minutes and then Mr. Swanson, superintendent of the Winter Brothers Tap Company, of Wrentham, successfully hardened several dozen high speed steel taps. Mr. Zavarine also had on display a number of complex Q-Alloy castings which brought forth much favorable comment. *H. E. Handy.*

BUFFALO CHAPTER

The first meeting of the Group in Lockport was held on Tuesday evening, April 27. A large and enthusiastic audience greeted Mr. Potts, the speaker of the evening. Mr. Potts is a Lockport man and his talk was of great interest to those present. Much enthusiasm was displayed as to where the next meeting would be held. Many prominent men of Lockport, Batavia and Buffalo were present. Mr. Roberts of Cleveland was also present. *G. J. Armstrong.*

CHICAGO CHAPTER

May 13—The Mechanism of the Fatigue Failure of Metals (Illus.) by H. F. Moore, research professor of engineering materials, University of Illinois, Urbana, Illinois. Attendance, 200.

Whether it was the logic in his presentation which comes from professorship; or the inspiration and goodfellowship that emanates from his contact which makes him popular wherever he goes—in the classroom, laboratory, industry, or meeting place; or the results of things accomplished that are attached to him; any or all of these may have contributed to the manner in which we of the Chicago Chapter listened to and were inspired by Professor Moore. It is good to be taught by a teacher especially in these days of high pressure and super salesmanship.

Exemplifying the thoroughness of research properly conducted, we saw the subject of fatigue failure as presented from three distinct viewpoints: that of the engineer who considers materials as being homogeneous and discontinuous; that of the metallographist who sees materials as continuous and inhomogeneous; and that of the physicist who treats materials as an aggregation of its smallest divisions. That such a presentation reached everyone in the large assemblage was evidenced by the fact that a continuous volley of questioning

followed Professor Moore's talk. The discussion finally had to be squashed to allow of the meeting being adjourned at a reasonable time.

The writer wishes to point out the fact that this lecture marks the culmination of the two years of Mr. Guthrie's chairmanship, during which time it was the chairman's greatest desire to raise the standard of the technical programs to a pinnacle not to be exceeded by any other similar society in the world. That he has been highly successful has been continuously attested by the excellent and exceptional attendance at all meetings which is not to be equaled to the writer's knowledge any place outside the Chicago Chapter. It is sincerely hoped that this standard will never be allowed to wane but continue to be improved with the experience of the society.

The important business transacted at the start of the meeting included election of next year's officers. F. C. Wheeler read the report of the nominating committee which submitted the following ticket which was unanimously approved by the membership:

Chairman ..... T. E. Barker
Vice-Chairman ..... A. F. Boissoneau
Secy.-Treas. ..... A. G. Henry
Executive Committee: J. C. Biemeck, J. J. Bossard, H. V. Cork, O. F. Carl, W. L. Levedahl.

It must be added that the annual outing to be held at the Hartman House, Wheeling, will mark the close of one of the most successful seasons that the chapter has enjoyed for some time, and it only remains for the mammoth convention in the fall, which this year's organization is fostering, to, in the words of Mr. Eisenman, "ring the bell." *J. A. Comstock.*

CINCINNATI CHAPTER

The regular April meeting of the Cincinnati Chapter was held at the Ohio Mechanics Institute on the evening of April 15.

There were forty-five guests and members present.

The chairman appointed Edward Wise, chairman, H. S. Binns and E. F. Ries, to serve as a nominating committee to select candidates for the various offices to be filled at the May meeting.

The chairman also announced the desire of the chapter officers to establish a night course in practical metallography and heat treatment similar to the courses offered by the Philadelphia and Los Angeles chapters. Tentative plans have already been submitted by Professor Enos of the University of Cincinnati and the whole-hearted support of the University of Cincinnati has been assured the chapter in the event the above courses are established.

W. R. Fleming, metallurgical engineer of the Andrews Steel Company, Newport, Kentucky, was then introduced and presented a paper entitled "The Relation Between the Steel Maker and the Steel Treater."

In his talk Mr. Fleming outlined the practical aspects of steel defects and their relation to the success of steel treating operations.

The following points were especially discussed: The effects of wild steel on heat treating results; pouring temperatures; general melting practice; various inclusions, metallic and non-metallic; seams and surface irregularities.

The paper was followed by a lively discussion in which the majority of those present took part.

The annual election of officers will take place at the next meeting of the chapter to be held at the Ohio Mechanics Institute on the second Thursday in May, or thereabout. *F. L. Martin.*

GOLDEN GATE CHAPTER

The March meeting of the Golden Gate Chapter of the society was held on the thirtieth at the Engineers' Club, San Francisco, in the form of a dinner meeting. The attendance was unusually large, due to the attractive program. There were sixty at dinner and over seventy at the meeting following.

The meeting was called to order promptly at 8 o'clock by Frank B. Drake, our chairman, who immediately introduced our guest of honor, R. M. Bird, the national president of the society. Mr. Bird gave us a most interesting talk, outlining the present work of the society and showing the prestige that it has now attained, due to the splendid work of the national committees, as well as the individual labors of the chapters. He described the new idea of group formations, with particular reference to the possibility of groups in nearby cities. He further expressed a very gratifying interest in the work the chapter has been doing toward metallurgical education, both in the regular meetings and in our course in ferrous metallurgy, which is now drawing to a close.

Mr. Bird was listened to with great interest by our members and at the end of the meeting took much time in meeting as many individual members as possible and discussing our efforts. The whole chapter feels deeply gratified in the interest of the national organization and particularly our president, who has come so many thousand miles to see us and whose thoughtful consideration of the present problems and future development of the society have greatly impressed us with the possibilities that are before us all.

The regular speaker of the evening was then introduced in the person of Dr. W. J. Crook, consulting metallurgist for Pacific Coast Steel Company and member of the Department of Metallurgy at Stanford University. Dr. Crook presented a most interesting paper on the "Microscopic Mechanism of Annealing," giving a short resumé of one phase of some extremely interesting research work that he has been conducting during the past year. Through his kindness a summary of this paper is included below, and, although it is necessarily without the many slides that served to illustrate the paper at our meeting, we feel it will be of interest.

SUMMARY OF PAPER

The general practical results sought by the operation of the steel annealing are threefold. (a) Refinement of grain size and structure. (b) Softening of the metal for purposes of machining or to undo hardening effects produced by previous operations. (c) Relieving of casting or forging strains.

The operation of annealing may be divided into two distinct steps; first, heating through some predetermined range of temperature to a certain maximum and hold at the maximum for a predetermined length of time; second, slow cooling, generally conducted in the furnace.

It is the purpose of this paper to discuss and illustrate just what goes on while the steel is going through the heating operation, from a physical structural point of view and what final results are obtained after the cooling operation under different conditions which may obtain during the heating stage.

In order that the photomicrographs which have been prepared may be thoroughly understood, it will be necessary to discuss very shortly the theory of heating for annealing.

When a piece of hypoeutectoid steel is slowly heated, no physical changes of any importance take place until the lower critical point (Ac_1) at about 1330 degrees Fahr. is reached. At this point two very important events happen. The pearlitic areas change over into austenite and also free ferrite begins to be absorbed by the austenite.

As the temperature is gradually raised above the Ac_1 point but below the Ac_3 point more and more ferrite is absorbed until at about 1550 degrees Fahr. (in the case of the particular steel, of which slides will be shown) the absorption of ferrite is completed and the steel is found to consist of only one material, that is, austenite. This austenite has, of course, a carbon content equal to that of the steel as a whole and does not contain 0.9 per cent carbon, as was the case of the austenite areas formed from the pearlite at a temperature just over the lower critical range.

Two series of photomicrographs were shown. In the first series the steel contains 0.46 per cent manganese and in the second series the steel has nearly the same carbon content but the manganese is 0.60 per cent. In both series, 3-inch cubes of steel were heated to various temperatures, starting at 1300 degrees Fahr. and quenched in cold water. Both steels contained about 20 per cent carbon.

In the case of the steel containing 0.60 per cent manganese no change in structure occurs in quenching from 1300 degrees Fahr. The Ac_1 of the steel was determined as 1330 degrees Fahr. The pearlite areas still remained pearlitic. On quenching from 1350 degrees Fahr. it was found that the pearlite areas had partly changed to austenite (martensite retained in quenched specimen). Careful examination showed that, in some cases, individual grains of pearlite were only partly changed, some were completely converted to austenite (martensite) and others were unaffected. Ferrite areas remained unchanged as the steel was quenched from higher temperatures, the areas occupied by martensite were found to be larger and larger, with a corresponding decrease in the remaining ferrite. When 1550 degrees Fahr. was reached no free ferrite remained. The steel as quench was completely martensite and fine-grained. In this particular steel, although careful analysis showed no alloy to be present, extraordinary hardness was developed in the completely martensitic state. The specimen quenched from 1550 gave a Brinell hardness number of over 600.

Referring to the series of specimens from the steel containing 0.46 per cent manganese a similar mechanism was found to occur except that a completely martensitic state could not be produced at the higher quench temperatures and some ferrite was apparently unabsorbed. The hardness developed was much less than in the previous case.

The influence of the presence of prematurely precipitated ferrite surrounding inclusions of manganese sulphide was illustrated and discussed in regard to its bearing on the complete refinement of steel.

The quenched cube specimens from the 0.60 per cent manganese steel were replaced in the furnace at a temperature equivalent to that from which they were quenched and then furnace cooled. A series of photographs were shown of these annealed specimens. These illustrations showed that complete grain refinement could only be obtained if the first heating temperature had been high enough to bring about complete absorption of ferrite. They also showed the coarsening of grain size which occurred when the initial heating was carried to a point over that sufficient to bring about complete absorption of free ferrite.

The meeting closed with a vote of appreciation of Mr. Bird's presence and of thanks to Dr. Crook for his most illuminating talk. There followed quite a long informal discussion with both the speakers and it was 11 o'clock before the rooms were finally cleared. *D. Hanson Grubb.*

INDIANAPOLIS CHAPTER

On Monday evening, March 22, hundreds of followers of the "Steel Treaters" who were unable to attend the monthly meeting of the local chapter were privileged to "listen in" from their home, as a very interesting program was broadcasted over radio station WFBM (268 meters), direct from the meeting, which was held at the auditorium of the Y. M. C. A. Most favorable reports have since been received, indicating that those who were unable to attend did take advantage of the radio.

R. M. Bird, our national president, in his talk, "Steel Brought to the Home," gave the radio audience, as well as the members and guests present, an innumerable list of reasons why practically every one should be interested in the development of steel, because of its wide use in every home, and the dependence of humanity upon that single metal. W. H. Eisenman, our national secretary, in his speech broadcasted gave the audience, visible and invisible, a brief outline of the "Romance of Steel" from the time of Adam and Eve, down to the present, and emphasized the great part which this organization has played in the wonderful progress of steel making and the science of steel treating.

An elaborate musical program, furnished by various members of the local chapter, completed the radio program.

Mr. F. R. Palmer, metallurgist for the Carpenter Steel Co. of Reading, Pa., presented a highly educational, informal talk on "Giving Steel a Chance," emphasizing many fundamental principles which the average man handling steel little thought of, but which are most essential to the successful, as well as economical, use of tool steels, etc. A very heated discussion followed and continued until a very late hour.

A special chicken dinner, attended by more than 150 members and guests, preceded the program and technical address. Many out-of-town guests were present and several new members were added to our roster. *C. H. Beach.*

On Monday evening, April 12, the members of the local chapter and their guests spent a most enjoyable evening at the Auditorium of the Y. M.

C. A., attending the dinner and regular monthly meeting of the local chapter.

Immediately following the dinner, which was attended by more than 125 "students" of the steel industry, Messrs. Durbin and Fristoe presented several snappy musical selections.

Mr. John F. Keller, steel specialist of The Purdue University of LaFayette, Indiana, put forth special effort toward inducing the steel worker to use proper thought in working out his steel problems claiming that a little thought along the correct lines would pay wonderful dividends for the man himself as well as his employer. His lecture was fully illustrated with lantern slides very appropriately selected, to fit in with his subject "Why Steel Warps and Cracks."

Harry B. Northrup, of the J. W. Kelly Company of Cleveland, Ohio, gave a most interesting shop talk covering practically every subject of interest to the man in the "Shop" and at the "Fire." Details of shop equipment, including furnaces, pyrometers, heating pots, and others, were given full consideration, and most of the men went back to their jobs with many new ideas. Many "Shop Kinks" in heating steel were presented.

Long discussions by many of those present were continued until the hour became late and the meeting was adjourned. *C. H. Beach.*

NEW YORK CHAPTER

The April meeting of the New York Chapter of the American Society for Steel Treating was held on April 21 in the Merchants' Association assembly rooms, Woolworth Building, New York. Messrs. W. P. Kirk and A. H. d'Arcambal of Pratt and Whitney Company, Hartford, Conn., addressed the chapter on the subject, "Alloy Steels in Machine Tools."

Since the fiscal year of the chapter is coming to a close, J. O. Rinek, the present chairman of the New York Chapter, called on the nominating committee, consisting of Messrs. L. R. Seidell, chairman, E. E. Thum and A. Hart, to give their report on nominations for the ensuing year. They reported that the officers nominated were as follows:

Chairman	Ancel St. John
Vice-Chairman	Charles McKnight
Secretary-Treasurer	T. N. Holden

Executive Committee

J. O. Rinek	E. C. Bain
E. P. Gaffney	Charles Von Schlutter
R. L. Johnston	J. J. Crowe
F. F. Lucas	

Mr. Kirk delivered a very interesting talk on construction and design of various types of machines. By means of lantern slides he showed the vast improvement made by the machine manufacturers in the design of machinery, and pointed out that this was mainly possible through the use of alloy steels. It was very interesting to note the great reduction in weight possible in gear construction, due to replacement of cast iron and cast steel gears with forged and heat treated alloy steel gears. This comparison was made on various types of machines, such as lathes, grinders, planers and shapers.

Mr. d'Arcambal then delivered a talk covering the subject from the metallurgical standpoint. His talk was very interesting, since he not only outlined the types of steels used in various applications, but gave the exact treatments applied and the resulting properties obtained. The information given by Mr. d'Arcambal was greatly appreciated by the members present, since some of it in the past has been treated by the tool and machine manufacturers as a trade secret and not divulged to the general public.

Unquestionably, those attending found the time devoted to this meeting well spent and are undoubtedly looking forward to another similar address that Messrs. Kirk and d'Arcambal can give to this chapter.

The meeting was well attended, there being about one hundred people present.

A lively discussion followed the address of both speakers.

John F. Myzalek.

NORTHWEST CHAPTER

The April meeting of the Northwest Chapter was held at the Manufacturers' Association, Wednesday evening, April 21. C. P. Richter of the Central Steel Company presented a paper on the Selection and Use of Alloy Steels. He discussed the properties of nickel, chromium, manganese, molybdenum, vanadium, silicon alloy steels, as well as nickel-chromium, chromium-vanadium, nickel-molybdenum, chromium-manganese-silicon, giving the types of work for which each is best fitted.

In selecting the steel for any particular work the condition under which it is to be used has to be considered. However, in order to bring out the properties of a steel, proper heat treating equipment is necessary and in a great many cases the basis for recommending an alloy steel depends on the equipment the plant has at its disposal for heat treating.

Mr. Richter also brought out the fact that at present physical testing and chemical analysis no longer are the only factors to be considered in determining whether a steel is in the proper condition to give the best service. Microscopic analysis is becoming just as important and in many cases more so than the other tests. Thus in carburizing steels the chemical analysis may be correct and still the steel will give poor results. In another case the hardness of the steel may be as required and yet the steel will fail in service. Microscopic examination of these types of failures showed that the grains of martensite were surrounded by troostite and the fracture occurred in this network of softer material.

After the presentation of the paper there was a good discussion, showing the interest the members had in the material that was presented.

Dr. O. E. Harder gave a report of the meeting of the executive committee with President R. M. Bird and Secretary W. H. Eisenman. The future policies of the society were presented as well as a brief report on the present activities.

L. J. Weber.

PHILADELPHIA CHAPTER

The regular monthly meeting of the Philadelphia Chapter was held at the Engineers' Club on April 23, preceded by the usual dinner, which everyone enjoyed.

The first paper of the evening was presented by Charles F. Hammond, metallurgist of the Winchester Repeating Arms Company. Mr. Hammond had for his subject "The Metallurgy of Small Arms Manufacture." This excellent paper was augmented by movies.

The second paper of the evening was presented by T. Y. Olsen, vice-president and treasurer of Tinius Olsen Testing Machine Company. His subject was "Recent Advances in Steel Testing Apparatus". Mr. Olsen's paper was well presented and of especial interest.

Both papers elicited some lively discussion.

The last Spring meeting is scheduled for May 28, when the chapter members are to be guests of the Midvale Company during the afternoon and at dinner. The regular business meeting, with election of officers for the coming year, is scheduled for the evening. *A. E. Donovan.*

PITTSBURGH CHAPTER

The Pittsburgh chapter held its regular May meeting on the evening of the 6th in the auditorium of the U. S. Bureau of Mines Building.

Vice-chairman John N. Ludwig, Jr., called the meeting to order in the absence of chairman W. H. Phillips and conducted a short business session.

As this meeting had been appointed as the annual "Shop Kinks" meeting, Mr. Ludwig, upon the completion of the chapter's business, turned the chair over to W. J. Merten under whose leadership the discussions of the evening were conducted.

Dr. V. N. Krivobok submitted the question of how to eliminate the banded appearance, as though cold worked, from a hot worked steel of 0.07 per cent carbon, 2.56 per cent manganese and 0.025 per cent phosphorus which had been annealed as high as 1700 degrees Fahr. without attaining the desired result. It was suggested to raise the annealing temperature. In this discussion of banded structures, an interesting practical experience was given. In testing thin blades which were attached to a revolving head on a wood-working tool and which revolved at a very high rate of speed, it was noticed that the blades which contained the banded structure would not retain a keen edge consistently on successive grindings. This irregularity was attributed to the impossibility of uniformly hardening the banded area.

Mr. Ihsen of the Westinghouse Electric and Manufacturing Company then told of his experience in testing retainer rings and discussed the difference between the forged and rolled rings.

James P. Gill of the Vanadium Alloys Steel Company was called upon to describe the best treatment for 14 per cent chromium and 2 per cent carbon steel used as die and punch steel. He advised a hardening temperature of 1650-1750 degrees Fahr. though it could be taken higher with care if necessary. After hardening, the steel could be tempered up to 500 degrees Fahr. without loosing its hardness. In heating this steel he recommended that it be packed to prevent surface oxidation in the furnace. In a discussion of hardness testing, it was stated that two hardened pieces of steel, one a high carbon and the other a high speed, both having the

same Brinell hardness number, might vary considerably under the Sclero-scope Test owing to the tendency of the high carbon steel to retain a some-what softer core, whereas, the high speed would be hard throughout and less elastic.

David Giles of the Latrobe Electric Steel Company gave an explana-tion of the proper heat treatment for stainless steel for cutlery use.

A. M. Cox of the Pittsburgh Commercial Heat Treating Company gave recommendations to prevent decarburization during the hardening of springs.

O. B. McMillen of the Pittsburgh Rolls Corporation told of the im-provement in the quality of the rolls of today giving comparative tonnages rolled per dressing today with those of twenty years ago.

Mr. Corson and Mr. George of the Edgewater Steel Company explained the action of a new spring which has been designed to take the place of helical springs for very heavy loads.

The chapter was pleased to welcome Mr. Gordon St. G. Sproule of Montreal who told of the formation of the new American Society for Steel Treating Group at Montreal. *Harry A. Neeb, Jr.*

ROCKFORD CHAPTER

The April meeting of the Rockford chapter was held at the Nelson House Wednesday the 21st. After the usual supper and short formal business meeting, the speaker of the evening, John Nelson of Barber, Cole-man Company, was introduced by O. T. Muehlemeyer, the chairman of the Program Committee.

Mr. Nelson spoke on the subject of "Keeping Track of Steel" and very close attention was accorded him for there are none among us who have not suffered more or less because some piece of steel has entirely lost its identity. The paper went into detail on methods of properly mark-ing the bars as they are received and later handling the pieces made from the bars in such a manner as to reduce to a minimum any chance of these pieces becoming lost, wrongly marked or having pieces of other grades of steel mixed with them.

The discussion following the paper was very general and showed that the audience had paid close attention and desired more light on particular phases of the subject. *R. M. Smith.*

SPRINGFIELD CHAPTER

The monthly meeting of the Springfield Chapter of the American Society for Steel Treating took place in the rooms of the Chamber of Commerce, April 6, 1926. Instead of presenting a paper on a definite subject, the offi-cers of the chapter decided to devote this meeting to a round table discus-sion of any topic pertaining to the treatment of steel which would be of interest to the members. It was felt that a sufficient number of problems of local character exist to make this meeting interesting and profitable to its members. The item selected for discussion was "Cyanide Hardening Practice for Small Commercial Steel Parts" The problems of proper clean-ing and preparing the parts previous to the process of cyanide hardening, the

approved methods of the process, as well as various ways of finishing the cyanide hardened parts, for instance, by means of parkerizing, were discussed at length.

As the members of the chapter were not entirely prepared for a thorough discussion of the cyanide hardening problem, and due to the interest that was shown at the meeting, it was decided to take up this same question at the next meeting in May. Several members of the chapter were requested to prepare cyanide hardened specimens treated under various conditions with respect to the time, the temperature and the nature of the compound, and submit a report of their findings at the next meeting.

In the absence of the chairman of the chapter, the discussion was directed by R. J. Allen. *N. A. Glaskowsky.*

SYRACUSE CHAPTER

The April meeting of the Syracuse Chapter of the American Society for Steel Treating was held in the Onondaga Hotel on the evening of April 12, at which time A. J. Porter, Jr., sales manager of the Heppenstall Forge Company at Bridgeport, Connecticut, addressed the chapter on the "Manufacture and Heat Treatment of Die Blocks."

The speaker started his address by showing motion pictures taken at the Pittsburgh plant of the Heppenstall Forge and Knife Company, which showed the melting, casting and forging of die block steel and, although we were only able to see about half of the three reels because of the projection lantern breaking down, we secured a very good idea of the Heppenstall practice.

Mr. Porter then proceeded to give a short history of the die block business, tracing it from the beginning, when high carbon crucible tool steel blocks were used exclusively, up to the present time, when heat treated alloy steel die blocks have been introduced. He then went into the manufacture of die blocks and told the reasons why the Heppenstall Company use presses, instead of hammers, for the working of the blocks. The method of working consists of forging the ingot to a billet, which is then cut off a little longer than the dimensions desired in the die block, and is upset under that dimension and then drawn back to the size specified on the order. In this way the blocks are worked through to the center.

Mr. Porter then went into the merits of heat treated die blocks, as compared with the die block bought in the annealed condition. Although the heat treated die block is harder and, therefore, more difficult to sink an impression, he stated that the hazard of cracking in hardening and scaling was eliminated and, furthermore, that the production on the heat treated die block was greater than that of the annealed block, which was heat treated by the customer. He went into proper heat treatment and methods of drawing die blocks and also the benefits of using heat treated shoes on the drop hammer.

This address by Mr. Porter was very well received and brought forth a lengthy discussion on design and heat treatment. He was given an enthusiastic vote of thanks by the chapter. *W. R. Frazer.*

On the evening of May 10, a large number of the members of the Syra-

cuse Chapter met for the annual meeting at Uhrig's and ate, drank, and made merry, as good fellows will when they get together.

Eugene Bock, retiring chairman of the membership committee, reported that during the year the membership of the chapter had been increased nearly thirty-five per cent.

Joe Driscoll, retiring secretary-treasurer, reported that the finances of the chapter were in first-rate condition.

Frank Wheeler, retiring chairman, announced the selections of the nominating committee for officers for the coming year. The men named were elected by unanimous vote. They are

Chairman—Walter Bolton, Brown Lipe Chapin, General Motors Division
Vice-Chairman—W. R. Frazer, Halcomb Steel Company
Secretary-Treasurer—S. P. Peskowitz, Halcomb Steel Company

Directors

Frank Wheeler—Kinman & Wheeler
L. M. Fenner—H. H. Franklin Mfg. Company
C. W. Smith—Oneida Community Ltd.
Wm. Bastion—Brown Lipe Gear Company
F. P. Cannon—Cannon Stein Steel Corp.

P. Peskowitz.

TRI-CITY CHAPTER

The joint dinner meeting of the Tri-City Chapter of the American Society for Steel Treating and the Quad City Foundrymen's Association was held on Thursday evening, May 20, in the Gold Room of the Blackhawk Hotel, Davenport. There were about one hundred members and guests present at this meeting.

R. W. Freeland, works manager of the Hubbard Steel Foundry Co., of East Chicago, Ind., addressed the joint meeting on the subject of "Steel Castings." Mr. Freeland's address comprised a general discussion of the general manufacture of steel castings reviewing the major facts with reference to this important industry. The speaker pointed out the fact that the tonnage capacity of the steel castings foundries of the United States was about one million tons per year, while the operating production of these foundries during the period since the war had averaged from sixty to seventy-five per cent of capacity. The greater portion of Mr. Freeland's talk covered the subject of foundry costs and management, in which fields Mr. Freeland is one of the outstanding figures in the steel foundry business.

The speaker stated that in his opinion the four basic divisions of efficient management control were as follows:

1. An efficient, yet not over costly, production department reporting directly to foundry manager.
2. Efficient inspection department reporting to foundry manager.
3. Apprentice training for the development of competent craftsmen and foremen.
4. Costs.

It was pointed out that the preparation of detailed costs sheets and reports was a very important and fine piece of work, but more important than

this was the necessity of presenting the cost sheet facts to the department heads that spend the money. By doing this the foremen will learn to know their own costs and will have a more intelligent viewpoint of the business of their department, which will enable them to lower their departmental costs.

Mr. Freeland pointed out that one of the greatest causes of heavy scrap losses was due to the poor engineering design of pattern equipment. It was stated that if the engineers and draftsmen had a greater knowledge of some of the problems of the foundrymen in overcoming difficulties of change of section, elimination of shrinkage, etc., scrap losses could be held at a minimum.

The discussion which followed Mr. Freeland's excellent paper substantiated the fact that the men present were very much interested in the presentation.

Stanley Brah, assistant director, apprenticeship training, Tri-City Manufacturer's Association, Moline, Ill., gave a short talk on the association's plan for a Tri-City apprenticeship training program which is being set up for the purpose of training craftsmen and future foremen for the factories of the Tri-City manufacturing district.

Louis Graham, an apprentice graduate of the Milwaukee apprenticeship school, gave a short but spirited testimonial of the value to be derived by the apprentice from a properly operated training school. *C. H. Burgston.*

WASHINGTON-BALTIMORE CHAPTER

On the evening of April 23, for the first time in a period of several years, a chapter meeting of the A. S. S. T. was held in Baltimore. The recent rapid recovery of the industrial situation in that city has again awakened interest in metallurgical problems and it was, therefore, decided to hold a meeting in Baltimore and to repeat the occurrence as often as the interest shown by Baltimore members would warrant. The chapter was fortunate in being able to have both Mr. Bird and Mr. Eisenman present at this meeting. It is also pertinent to record that the efforts of Emil Gathmann and other members of the Baltimore Chapter were largely responsible for the success of the meeting.

Following a dinner at the Emerson Hotel, at which Mr. Gathmann was host, the meeting was opened in the rooms of the Engineers' Club of Baltimore; this organization had tendered its assistance and cooperation in carrying out all arrangements. Following a brief welcome by a member of the executive committee of the Engineer's Club, chairman McKinney introduced Mr. Bird as the first speaker of the evening. Mr. Bird reviewed the rapid growth of the society, the basic relationship upon which this growth had developed, and then discussed in a general way the materials engineering features associated with every day heat treatment problems.

Mr. McKinney next introduced H. J. French, who gave an excellent outline of the problems confronting the steel treater, under the title of "The Application of Heat Treated Steels to Industrial Uses." Mr. French described the important factors affecting the behavior of steels in respect to performance both in service and in preparation in the shop for service as

1—Quality
2—Composition
3—Heat Treatment

Further subdivision of the third factor was made into the temperature from which cooling occurs; the time at that temperature and the manner of cooling.

Quality is a general term applied to all those properties that result from influences other than those included in headings 2 and 3 and that affect the performance of any steel. Quality is not subject to quantitative treatment as are the other factors. Furthermore, that quality which is desirable in steel for one purpose is not necessarily best suited to steels for other purposes. Among the properties which affect the quality of any steel are included the size, nature and distribution of metallic and non-metallic components, segregation, amount of working in forging or rolling, temperature of working, etc. As a specific example of the effect of poor quality, Mr. French showed photographs and macro- and microstructure of a crankshaft, in which failure had been caused by a combination of porosity and inadequate mechanical work. It was pointed out, however, that in many cases the causes of difficulties resulting in failure were not so easily traced. In one instance two groups of spring steel of identical composition, insofar as the elements usually analyzed for were concerned, one made by the open-hearth process and the other in the electric furnace, required appreciably different heat treatment for the development of identical physical properties; the reason for this peculiarity was not clear but in every instance the tempering temperature for the open-hearth material was higher than for the electric furnace product. Another instance cited was the great differences in performance on heavy-duty cutting, of high speed steel lathe tools made from different lots having almost identical composition. Reference was also made to the differences in the results obtained when case-hardening articles of "normal" and "abnormal" steels; it has been shown in this work that the details of the steel-making operation have a very important bearing upon the occurrence of the soft spots which are so prevalent in the "abnormal" steels.

In considering composition, Mr. French mentioned the carbon and simple alloy structural steels, the use of tungsten and chromium in tool and magnet steels, of silicon in transformer steels and cobalt in magnet steels. In order to better describe the use of these and other elements, a series of illustrations was given. Assuming a case-hardened gear to be failing by crushing in service, it was explained that raising the carbon content of the raw material would increase the hardness of the core and furnish a stronger backing for the case but that brittleness would ensue. Alloy additions in such instances were helpful and nickel possessed the advantage of lowering the required quenching temperature, thereby reducing scaling and distortion, thus aiding manufacture as well as performance in service. In the case of forming dies containing about 0.60 per cent carbon, 1.75 per cent nickel and 0.75 per cent chromium, failure had been observed, resulting from fire-cracking. Increase in chromium or in nickel or both was not effective, but the addition of molybdenum, which increases the tempering temperature at which softening occurs, was productive of the desired increased life. Mention was also made of high-strength parts of such form that machining was

required after heat treatment and in this connection a chart was shown, giving the relationship between tensile strength and tool endurance under severe cutting conditions for a number of good structural alloy steels. It was shown that the order of tool life in a group of steels of equal tensile strength might vary greatly according to the specific tensile strength selected. Thus, the difference in machinability of alloy steels when translated into production may be of great economic importance.

In discussing the effect of heat treatment Mr. French remarked that there were frequent occurrences of highly stressed structural members giving trouble by deforming and that it was often possible, due to the great variation in elastic limit for a given tensile strength according to the heat treatment used, to solve such problems merely by heat treatment modification without change of material. A further instance of the importance of heat treatment is found in the pronounced effect of both time at high-heat temperature and of the high-heat temperature itself upon the results obtained from high speed steel lathe tools. There are here, of course, other factors to be considered, for a balance must be secured between performance, brittleness as affected by hardening temperature, oxidation of tools, and deterioration of furnace equipment.

In considering the effect of the manner of cooling, the work of R. H. Smith upon the low carbon steels was described, pointing out the fact that tensile strengths of 100,000 pounds per square inch and over had been secured by quenching 0.08 to 0.12 per cent carbon steels in water under high pressure. It was shown that close to 70,000 pounds per square inch tensile strength could be secured from ingot iron in this manner. Referring again to troubles with case-hardening steels, Mr. French stated that increasing the severity of the quench (in the case of steels which, upon quenching in tap water, would show many soft spots) by quenching in 10 per cent brine, would result in a surface almost free from soft spots. The influence of mass in heat treatment was well illustrated by figures for a 0.45 carbon steel in sizes from $\frac{1}{16}$-inch diameter to 3 inches diameter when quenched from 1600 degrees Fahr. into water and into oil. When using the former medium, the tensile strength ranged from 269,000 down to 116,000 pounds per square inch at the center, whereas with the latter medium the range was only 130,000 to 110,000 pounds per square inch.

In the discussion many problems were considered, among them the heat treatment of dies by pressure quenching, selection of material for air-hardening rivets and for rivets to resist corrosion, the relation between the method of heat treatment of carbon steels and their hardness, micro-structure and resistance to wear, variation in the performance of high speed steel of different compositions, due to variation in heat treatment and the effect of size, nature and distribution of non-metallic inclusions upon various types of steels.

Following the discussion, Mr. Eisenman discoursed upon the financial and technical strength of the society and the value of contact with outside speakers and of local discussions to the members of each chapter. He referred to the nature of the general and sectional meetings, their value to

the individual and the increase in their scope which has occurred during recent years. Reference was also made to the activity of the various national committees, particularly the work of the Recommended Practice Committee and the success that had attended its efforts. A description was also given of the service to the membership through the medium of TRANSACTIONS and the Data Sheets and a cordial invitation extended to all those who were present who desired to be of service to the Society and in return have the Society of service to them, to become affiliated with it. *Jerome Strauss.*

FORT WAYNE GROUP

Professor John F. Keller, steel specialist from the engineering extension department at Purdue University, explained in a practical way many phases connected with the treating of steel before a dinner meeting of the Fort Wayne group of the American Society for Steel Treating held at the Y. M. C. A. April 28.

Besides the talk by Professor Keller, whose subject was "What Makes Steel Warp and Crack," there was a short address by F. C. Smith, chief chemist at the local plant of the International Harvester company, who spoke on "The Most Common Forms of Microstructure." Both of the speakers told of many practical methods in the treating of steel and following the talks an open forum was held.

At a short business session which immediately followed the dinner, F. C. Smith was elected secretary-treasurer of the Fort Wayne group. He succeeds A. L. Cramp, who was named temporary secretary when the group was organized a few months ago.

A nominating committee to select candidates for office was appointed and is composed of J. A. Hanson, Charles Grimes and D. A. Conroy. An auditing committee was also appointed, this comprising J. H. Clark, H. B. Carson and L. J. Webster. Election of officers will probably be held at the next meeting, which is scheduled for the latter part of May. Some prominent metallurgist will be invited to address the group at that time on "Tool Steels."

Four new members were taken in last night and more than 80 persons were present. G. E. Tibbets, temporary chairman, presided.

THE DUROMETER—AN INSTRUMENT FOR TESTING HARDNESS

(Continued from Page 932)

steels contained 0.10, 0.30, and 0.80 per cent carbon. They were tested in the following condition: (1) as received; (2) annealed; (3) normalized; (4) quenched; (5) quenched and drawn.

It will be noted that the steel containing 0.30 per cent carbon is slightly harder after quenching than the sample containing 0.80 per cent carbon. This is undoubtedly due to its having been quenched in water while the 0.80 per cent carbon steel was quenched in oil. Its Brinell hardness was 444 and that of the eutectoid steel 363.

NEW MEMBERS OF THE SOCIETY

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member; and Sub represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

(New Member List Continued from May Transactions)

NORTON, E. M., Jr., (J-3), student, University of Cincinnati; *mail* 1717 Central Ave., Ashland, Ky.

O'HARA, T. C., (M-1), forgesmith, Naval Aircraft Factory; *mail* 1616 Summer St., Philadelphia.

O'KEEFFE, P. O., (M-4), foreman, heat treat, Russell, Burdsall & Ward Bolt and Nut Co.; *mail* 245 Locust Ave., Port Chester, N. Y.

ONDERDONK, W. N., (M-4), assistant superintendent drill department, Ingersoll-Rand Co.; *mail* 627 Lafayette St., Easton, Pa.

ORGAMETALL, (Sb-1), Lutschnokov 4, Moscow, United Socialist Soviet Republics.

OWEN, R. J., (M-4), superintendent, Thomas & Skinner Steel Products Co.; *mail* 425 Harmon St., Indianapolis.

PARKER, W. B., (M2), chief chemist, British Thomson Houston Co., Ltd., Rugby, Warwickshire, England.

PEDERSEN, P. O., (M-4), sales manager, The Linograph Co., Davenport, Iowa.

PENROD, W. W., (M-4), metallurgist, International Harvester Co.; *mail* 776 49th St., Milwaukee.

PETERSON, A. H., (M-4), treasurer and manager, Peterson Spring Co.; *mail* 1660 Beard St., Detroit.

PIERCE, F. H., (M-2), chief draftsman, Dycast Steel Co., Collinsville, Conn.

POWERS, EDWARD, (J-4), student, Drexel Institute; *mail* 1817 Gladstone St., Philadelphia.

PRATT, P. E., (M-4), master mechanic, H. K. Mulford Co.; *mail* 1544 S. 53rd St., Philadelphia.

PHILADELPHIA ELECTRIC CO., (S-11), C. E. Russell, industrial heating engineer, Philadelphia.

PURNELL, C. G., (M-3), inspector, metallurgical department, Carnegie Steel Co., 571 Frick Annex Bldg., Pittsburgh.

QUEEN, J. W., JR., (M-3), metallurgist assistant, Crucible Steel Company of America; *mail* 22 Duncan Ave., Jersey City, N. J.

RAISLEY, W. A., (J-4), student, laboratory assistant, Ingersoll-Rand Co.; *mail* Y. M. C. A., Easton, Pa.

REMENSNYDER, G. W., (A-4), salesman, Colonial Steel Co.; *mail* 18 Perryview Ave., Pittsburgh.

RENFREW, PAUL, (M-4), chief draftsman, S. F. Bowser & Co., Ft. Wayne, Ind.

REYNOLDS, H. W., (M-4), district representative and manufacturers agent; *mail* 634 St. Clair Ave., Cleveland.

RICHARDS, JAMES, (M-4), production foreman, International Harvester Co.; *mail* 1326 Lynn Ave., Ft. Wayne, Ind.

RIDEOUT, W. B., (M-3), steel treater, E. W. Bliss Co.; *mail* 80-19th, Jackson Heights, Long Island, N. Y.

RODGERS, J. J., (M-4), superintendent, International Harvester Co., Ft. Wayne, Ind.

ROGERS, F. P., (M-1), treasurer, Rogers Drop Forging Co., Rochdale, Mass.

RUTH, C. L., (M-3), assistant superintendent, The Carpenter Steel Co., Reading, Pa.

SANDBERG, R. M., (M-4), executive department, Columbia Tool Steel Co., Chicago Heights, Ill.

SANDERSON, E. P. Co., (S-4), R. H. Sanderson, treasurer; *mail* P. O. Box 5321, Boston.

SCHAUM, CARL, (M-3), engineer, Fletcher Works, 2nd & Glenwood Ave., Philadelphia.

SCHEID, A. J., JR., (M-4), metallurgist, Columbia Tool Steel Co.; *mail* 1342 Vincennes Ave., Chicago Heights, Ill.

SCHUTE, F. A., (M-12), laboratory assistant, United Alloy Steel Corp.; *mail* Y. M. C. A., Canton, Ohio.

SHUTT, W. H., (M-4), melter, American Chain Co.; *mail* 315 York St., Hanover Pa.

SMITH, H. M., (M-3), chief metallurgist, Wyckoff Drawn Steel Co., Ambridge, Pa.

SCOTT, C. R., (M-4), president, Gill Screw Associates, Inc., Westboro, Mass.

SCHRENK, H. W., (A-4), salesman, The Bourne Fuller Co., 1614 Hanna Bldg., Cleveland.

SHIRK, B. H., (A-1), salesman and metallurgist, United Alloys Steel Corp., Canton, Ohio.

SOHNER, E. H., (M-4), assistant superintendent, International Harvester Co.; *mail* 922 Wildwood Ave., W., Ft. Wayne, Ind.

SPITZ, J. C., (M-3), superintendent of machine department, Stecher Lithographic Co.; *mail* 274 N. Goodman St., Rochester, N. Y.

STATZ, F. A., (M-4), chief inspector, International Harvester Co.; *mail* 1116 Division St., Ft. Wayne, Ind.

STEER, A. E., (A-2), salesman, Thos. Firth & Sons, Ltd.; *mail* G. P. O. Box 627, Toronto, Ontario.

STEPHENSON, W. B., (M-4), heat treat department, Detroit Gear & Machine Co.; *mail* 4604 12th St., Apt. 2, Florian Apts., Detroit.

STEVENS, D. A., (M-3), shop foreman, Monticello Oil Co., Fillmore, Calif.

STICKLEY, G. W., (M-4), laboratory assistant, Aluminum Company of America; *mail* 303 Brackenridge Ave., Brackenridge, Pa.

STRAUB, H. E., (M-4), general foreman assembly, International Harvester Co.; *mail* 801 Pasadena Dr., Ft. Wayne, Ind.

TAYLOR, A. E., (M-1), metallurgical assistant, The American Rolling Mill Co.; *mail* 2509 Central Ave., Middletown, Ohio.

THOMAS, J. R., (M-4), president, Thomas & Skinner Steel Products Co.; *mail* 425 Harmon St., Indianapolis.

THOMPSON, JOHN, (M-4), foreman blacksmith, Philadelphia Electric Co.; *mail* 1943 S. 57th St., Philadelphia.

TIBBITS, G. E., (M-4), general superintendent, S. F. Bowser & Co.; *mail* 1201 E. Pontiac St., Ft. Wayne, Ind.

TRACEY, FLETCHER, (M-4), foreman in hardware department, The Baldwin

Co.; *mail* 515 E. 12th St., Cincinnati.

UHLMEYER, G. A., (A-4), industrial engineer, Peoples Power Co.; *mail* 634 45th St., Rock Island, Ill.

VAN VECHTEN, G. C., (M-3), plant engineer, Stecher Lithographic Co.; *mail* 274 N. Goodman St., Rochester, N. Y.

WALLACE & SONS MFG. Co., R., (S-5), C. D. Morris, superintendent, Wallingford, Conn.

WALTERS, W. E., (M-4), hardener, Meisel Press; *mail* 33 Division St., Chelsea, Mass.

WARD, C. H., (M-4), experimental department, Bethlehem Steel Co.; *mail* 10 Finady Ave., Bethlehem, Pa.

WARR, H. G., (M-4), assistant general manager, The P. & M. Co., 1310 Railway Exchange, Chicago, Ill.

WARREN, MARK, (M-4), assistant foreman, International Harvester Co.; *mail* 2505 Fox Ave., Ft. Wayne, Ind.

WEBSTER, F. H., (M-5), tool superintendent, International Harvester Co.; *mail* 1814 E. Pontiac St., Ft. Wayne, Ind.

WEBSTER, L. J., in tool room, International Harvester Co.; *mail* 1903 Oxford St., Ft. Wayne, Ind.

WEIL, J. M., (M-4), assistant in forge department, Ingersoll-Rand Co.; *mail* 337 Bushkill St., Easton, Pa.

WEIS, A. M., (M-4), superintendent, Gerlinger Electric Steel Castings Co.; *mail* 595 Oakland Ave., Milwaukee.

WELCH, H. F., (M-4), foreman, International Harvester Co.; *mail* P. O. Box 250, Ft. Wayne, Ind.

WIEDEMANN, O. F., (M-4), machinist, Wiedemann Machine Co.; *mail* 1815 Sedgley Ave., Philadelphia.

WILCKEN, E. E., (M-4), time study department, (in charge), International Harvester Co.; *mail* 2110 Hensch St., Ft. Wayne, Ind.

WILDE, M. L. C., (A-4), district manager, Colonial Steel Co.; *mail* 308 N. 15th St. ,Philadelphia.

WILE, R. S., (M-4), industrial engineer, Surface Combustion Co.; *mail* 4331 S. 167th St., Flushing, N. Y.

WILLIAMS, J. P., (M-5), tool hardener, Chicago Pneumatic Tool Co.; *mail* 449 Peterboro St., Detroit, Mich.

WILLIAMS, M. L. (M-1), physical testing, Henry Disston & Sons, Inc.; *mail* Bridgewater P. O., Bucks Co., Pa.

WILLIAMS, H. T., (J-3), student, Case School of Applied Science; *mail* 2073 Adelbert Rd., Cleveland.

WILEY, R. E., (J-3), student, University of Minnesota; *mail* 1115 4th St., S. E., Minneapolis.

WILSON, E. F., (J-4), student, Massachusetts Institute of Technology; *mail* 29 Toxteth St., Brookline, Mass.

WITMER, L. F., (M-3), associate professor of metallurgy, Lafayette College, Easton, Pa.

WISE, R. A., (M-4), tool room foreman, The John Lees Co., Indianapolis.

WOOLRIDGE, W. J., (M-3), manager, electric sheet department, Mansfield Sheet & Tin Plate Co.; *mail* 325 West 3rd St., Mansfield, Ohio.

ZAVOICO, S. V., (M-5), metallurgist, Bethlehem Steel Co.; *mail* 448 Vine St., Bethlehem, Pa.

ZIESING, HENRY, (M-4), assistant manager of sales, Midvale Co., Nicetown, Philadelphia.

ZIMMERMAN, FRED., (M-4), heat treater, Standard Die & Tool Co.; 8th & Carleton Sts., Berkeley, Calif.

ZIMMERMAN, P. W., (J-3), laboratory assistant (student), Ingersoll-Rand Co.; *mail* 677 Barrymore Ave., Phillipsburg, N. J.

ZUBKO, J. K., (M-1), Skrznka Poczтowa 109, Warsaw, Poland.

ZURBACH STEEL CO., L. E., (S-3), L. E. Zurbach, president, Boston.

DISCUSSION—IRREGULAR CARBURIZATION OF IRON AND IRON ALLOYS—THE CAUSE AND PREVENTION

(*Continued from page 928*)

abnormality of steel to spring steel or other high carbon steels, I would like to inform him that there is probably not a plant in the country that has given more attention and more careful study to spring development than the Westinghouse Electric and Manufacturing Co. We work our springs, particularly those applied for drives on electric locomotives, harder than practically in any other service and we have not found any abnormality after we selected and coiled and treated the steel in the proper manner, which included rolled steel bar inspection at the mill, supervision of coiling and adjusting of spring at the spring plant, and supervision of heat treating at the W. E. & M. Co.

Author's Closure

In reply to Mr. Shepherd I again state that I have not found a single case of failure of steel to respond to proper carburizing practice, nor have I encountered one that acted abnormally. It is for this reason that I have taken the stand, and question the existence of such abnormal steel.

My statement as to Fe_3C going into solid solution with iron *above* 700 degrees Cent., necessarily requires the Fe_3C having formed, since I stated before that it takes a higher temperature for this chemical reaction to take place, any Fe_3C going into solution at *slightly above* 700 degrees Cent. must be in the steel.

In regard to the die-surface, Fig. 1 is a photograph at 5 diameters enlargement and not a micrograph. The surface is not etched. The pitted condition of gear teeth developed in service and which are due to a roughening of the surface by an irregular concentration of carbide, and is mentioned under paragraphs dealing with Preparation of the Iron and Steel Parts. While the pitting in the container during carburizing is due to a dissolving action of the fusible slag mentioned, both are of a very deleterious character and should be recognized as distinctly different causes for pitting.

Long time holding of objects at carburizing heat naturally produces entirely different results. In an exacting and highly productive practice, these precautions mentioned by me are important and cannot be minimized.

Employment Service Bureau

Address answers care of A. S. S. T., 4600 Prospect Ave., Cleveland, unless otherwise stated.

POSITIONS WANTED

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PRACTICAL HARDENER. Blacksmithing and hardening of dies and tools of any kind, high speed or carbon steel. Can make furnaces and repair same, if necessary. Address 5-10.

FORGE SHOP FOREMAN, practical and competent, desires position. Has had 22 years' experience in all kinds of hammer forging, hardening, heat treating and tool maintenance. At present employed, and reasons for change are very good. Will furnish very good references. Address 5-15.

METALLURGIST desires connection with growing concern as assistant to superintendent. College education and five years' experience in the analysis heat-treatment, manufacture and control of steel and its alloys. Capable organizer and company man. Address 6-5.

METALLURGIST desires position as superintendent of steel plant. College graduate. Has had extensive experience in blast furnace, open hearth and electric furnace practice, having specialized in the alloy steel industries. Address 6-25.

METALLURGIST-CHEMIST, 30, married, desires change. Eight years' experience, embracing alloy steels, nonferrous alloys; blast furnace, foundry and steel plant materials; knowledge of metallography and heat treatment; desires responsible position of opportunity in laboratory, plant or office, utilizing training. Industrious, conscientious; possessing initiative and ability to produce. University graduate. Philadelphia district preferred. Available on short notice. Address 6-35.

POSITIONS OPEN

WANTED: Young man with technical training and one or two years' practical experience in machine shop, steel mill or laboratory, to develop into sales work on special and alloy steels.

Answer in full, giving age, nationality, religion, marital state, education and experience. State salary desired. Address 5-20.

YOUNG MAN WANTED for sales work in Boston vicinity with dealer in furnace and allied equipment. Some engineering training preferred. Address 5-25.

SALESMAN—Technical man preferred with experience in carburizing and heat treating practice. Position requires traveling. Previous sales experience preferred but not essential. State experience, age, salary expected. Address 5-30.

SALESMAN. Graduate of mechanical or electrical engineering course, preferably from class of '23 to '26, for sales and service work on Hump and Homo Heat Treating Furnaces. Short training period necessary before active field work. Write, giving age, marital state, education, schools attended, experience, etc. State salary expected and enclose photograph. Address 6-15.

METALLURGIST and Automotive Engineer, who is expert in the heat treatment of steel, wanted to co-operate with all automotive manufacturers by studying their needs for new patented equipment for automatically controlling temperatures. In replying describe experience in a general way and give detailed facts about experience with temperature measuring instruments. Address 6-20.

WANTED—Young man for metallurgical and analytical work in laboratory on ferrous and nonferrous metals. Apply in writing, stating experience and training. Address 6-40.

SALESMAN WANTED—To sell Ferro Alloys to steelmakers. Must have some knowledge of steel mill practice. Not over 40 years of age. Address 6-60.

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FOR SALE—One Bausch & Lomb F-2 Microscope fitted with two objectives 16mm and 4mm and one eyepiece 7.5x, including revolving double nosepiece to carry the two objectives. In handsome walnut case with brass lock and key. Excellent condition. Address The Columbus Gear & Pump Company, 318-350 E. Second Ave., Columbus, O.

1 Eaton Electric Furnace, new, at a bargain price. Address 6-55.

Lot of Leeds and Northrup Hump Furnaces in good condition. Address 6-50.

FOR SALE: Exceptional Leeds & Northrup Furnaces. Guaranteed Brand New. Will sell at very great sacrifice. L & N "Hump" Heat Treating Furnace—1 No. 8058 Furnace, inside dimensions, 8½ inches in diameter and 22 inches deep. One No. 8551—F—8 Recorder. L & N Drawing Furnace—1 No. 9262—24 furnace, inside dimensions, 12 inches in diameter and 24 inches deep. One No. 8970 Control Panel. One No. 8571—D—D—39 Controller. These furnaces were intended to through-harden automobile crankshafts made of ball-bearing steel which have been eliminated in the design and which has made the furnaces unnecessary. They were used only in a test, for a few hours. Address 3-40.

Items of Interest

R. F. FISKE, for several years manager of the R. D. Nuttall Co., eastern office at Philadelphia, has been appointed sales manager, in place of Q. W. Hershey. J. E. Mullen, of the home office sales force, has been made assistant sales manager.

W. C. Peterson has been appointed metallurgical engineer of the Donner Steel Co., Inc., Buffalo, with offices in Detroit. For some years he has had charge of the metallurgical department for Packard Motor Car Co., and for the last two years was engaged in a consulting capacity for several firms in Detroit and vicinity.

Simonds Saw & Steel Co., Fitchburg, Mass., has moved its Seattle branch from 410 Occidental avenue to the Moran building, First avenue south and Holgate street, where larger quarters are available.

A booklet describing its refractory cements has been issued by the Norton Co., Worcester, Mass. Application of the several grades are suggested and advantages from use are given.

Theodore H. Harvey, vice-president Ohio Steel Foundry Co., has been appointed general sales manager, covering both the Springfield and Lima plants of the company. He has been connected with the Springfield plant for eight years, having been works manager until he was made vice-president three years ago. F. G. Wright, another vice-president, and J. R. Hastings, secretary, both of Lima, who have been in the business for many years, have withdrawn from active work. V. T. Hohaus has been appointed works manager at the Springfield plant and W. J. Hayes, sales manager. Both have been connected with the plant for some time.

J. C. Woodson, formerly section engineer in charge of industrial heating, has been appointed manager of the industrial heating engineering department, Westinghouse Electric & Mfg. Co. A graduate of Oklahoma State University, Mr. Woodson entered the service of the Westinghouse company in 1915. He was assigned in 1916 to the circuit breaker section of the supply engineering department. Since 1920 he has been engaged in industrial heating work.

P. E. Floyd has been appointed manager of sales in charge of the Chicago office and warehouse, Ludlum Steel Co., Watervliet, N. Y. He succeeds H. W. Edwards, who has been transferred to Southern territory, with headquarters at Houston, Tex.

The Brown Instrument Company, Philadelphia, has available for those interested, Catalog No. 15 which is said to contain up-to-the-minute information on the latest developments of pyrometry and contains complete descrip-

(*Continued on Page 36 Adv. Sec.*)

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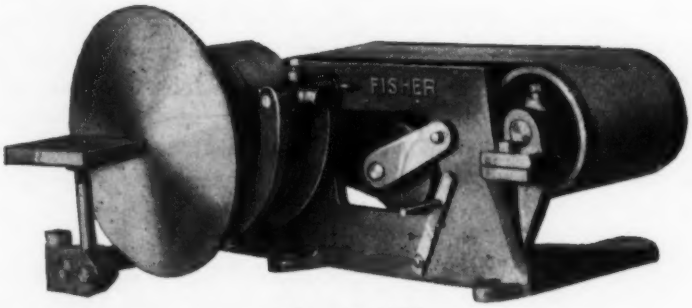

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tion and illustrations of Brown Pyrometers of all types, also thermocouples, protecting tubes, switches and other accessories, with prices. About 120 illustrations, many in 5 colors, are contained in this 80-page booklet.

The University of Michigan, Ann Arbor, Michigan, has issued a bulletin containing its program in Chemical Engineering and Graduate Courses in General Chemical Engineering, Metallurgical Engineering, Gas Engineering and Organic Chemical Industries. It also sets forth the facilities for instruction and research available to the student, the laboratory equipment, library conveniences and additional advantages such as fellowships, summer employment, visits of inspection and the solution of everyday industrial problems of general interest which results in mutual benefit. An outline of the undergraduate courses and a schedule for a four-year program in Chemical Engineering are given.

The International Nickel Company, 67 Wall Street, New York City, has available Bulletin No. 3 entitled "Heat Treatment and Applications of Nickel and Nickel-Chromium Steels" by Thomas H. Wickenden. Binders to facilitate the binding of these bulletins and increase their reference value are also available for those desiring the loose-leaf type binder for filing nickel steel bulletins.

Dr. V. N. Krivobok, Associate in the Bureau of Metallurgical Research of Carnegie Institute of Technology, has been awarded a grant of $500.00 by the Iron and Steel Institute of Great Britain to assist him in carrying out a photomicroscopic study of recrystallization of metals after cold-working, according to an announcement. Public announcement of the award, which comes from the Carnegie Research Fund of the Iron and Steel Institute, was made at the annual meeting of the Institute in London, on May 6 and 7, 1926.

Dr. Krivobok has been a member of the staff of the Bureau of Metallurgical Research of Carnegie Tech since its organization by President Thomas S. Baker two years ago.

"Steam Economy" is the title of a new 56-page bulletin issued by the Republic Flow Meters Company, 2240 Diversey Parkway, Chicago. This is a compilation of the experiences of their engineering force during the past ten years on the subject of methods for reducing steam cost. It is well-illustrated and shows a typical Republic installation. Sent upon request without obligation.

The Bristol Company, Waterbury, Conn., has available Catalog No. 1700 which describes their electric Tachometer, a device for recording and indicating the speed of rotation of any piece of revolving machinery. This equipment consists of a magneto and a voltmeter. Its advantages are enumerated and the method of its operation described and illustrated. Sent upon request.

H. Audino, formerly with the saw department of R. Hoe & Co., Inc., New York, is now with the engineering department of the Edison Storage Battery Company, Orange, N. J.

(Continued on Page 38 Adv. Sec.)

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Effective April 1, 1926 the name of The A. H. Wolff Gas Radiator Company is changed to American Gas Products Corporation in order more clearly to define the extent and variety of the gas heating equipment manufactured and distributed by the former company. The American Gas Products Corporation will continue as sole distributor of ideal gas boilers manufactured by the American Radiator Company. The same high quality of merchandise will be maintained. Address 376 Lafayette Street, New York.

The Botfield Refractories Company of Philadelphia announces that the Standard Asbestos and Cork Company, of 541 South Troost Street, Tulsa, Oklahoma, has been appointed distributor for its Adamant fire brick cement, the original high temperature cement. They will cooperate with users of fire brick who are interested in prolonging the life of fire brick construction, and in reducing refractories maintenance costs.

The International Nickel Company of New York City has for distribution bulletin No. 4 on "Making Steel Castings Stronger" and bulletin No. 5 entitled "The Mill Inspection of Steel." Sent on request gratis.

Frank A. Hall has joined the Dempsey Furnace Division of the W. N. Best Corporation, 11 Broadway, New York City.

Mr. Hall has been active for the past five years in industrial furnace work in Philadelphia. Prior to entering the industrial furnace field he was engaged in metallurgical work for Wright-Martin Aircraft, Driver-Harris, and the New Jersey Tube Company.

H. S. Brainerd, metallurgist of the Phillipsburg and Easton plants of the Ingersoll-Rand Company, sailed for Sweden on June 3, aboard the new Diesel engine liner "Gripsholm". During his two months' stay abroad he will visit steel plants in Sweden, Belgium, Germany, England, and France.

The Stanley P. Rockwell Company, 66 Trumbull Street, Hartford, Conn., has available Bulletin No. 2605 entitled "A Guide for Those Contemplating the Purchase of New Heat-Treating Equipment or Improving Heat-Treating Furnaces Now in Use." This bulletin pertains chiefly to hardening equipment for tools, dies, taps, gears, etc. Sent on request.

Effective June 1, Lawrence K. Diffenderfer tendered his resignation as secretary and treasurer of the Vanadium Corporation of America. Mr. Diffenderfer is leaving the Vanadium Corporation of America to engage in special accounting, tax work, industrial plant and mine valuation, and work of that nature. He is to be succeeded by Edgar R. Alpaugh. P. J. Gibbons, at present chief clerk of the Bridgeville plant of the Vanadium Corporation of America, has been elected assistant treasurer. J. A. Miller, Jr., at present general sales engineer, will become assistant general manager of sales with headquarters in New York. H. T. Chandler, assistant to the president, who is now located in Detroit, will be transferred to the New York Office, in the same capacity. C. N. Dawe, at present with the Studebaker Corporation of America, at Detroit, will become affiliated with the Vanadium Corporation of America as manager of the automotive division, with headquarters in Detroit. T. N. Bourke, at present district sales manager, will become assistant manager of the automotive division with headquarters in Detroit.

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Transactions of American Society for Steel Treating

Vol. IX June, 1926 No. 6

FEATURES

Some Comparisons Between Rockwell and Brinell Hardness—
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Progressive Carburization in Rotary Electric Furnaces—
H. E. Martin 933

The Constitution of Steel and Cast Iron—Part I— *F. T. Sisco* 938

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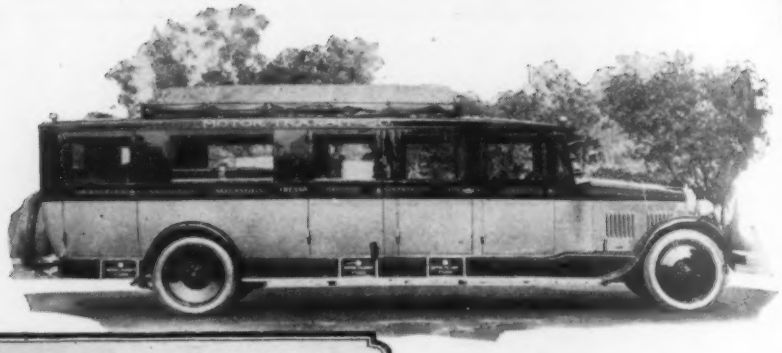

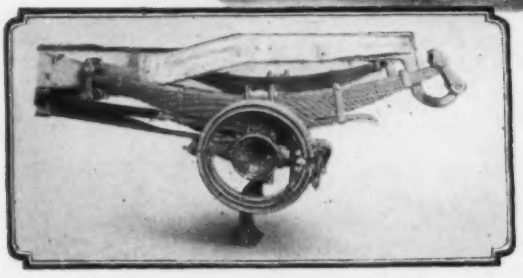

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OF THE

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RAY T. BAYLESS, *Editor*

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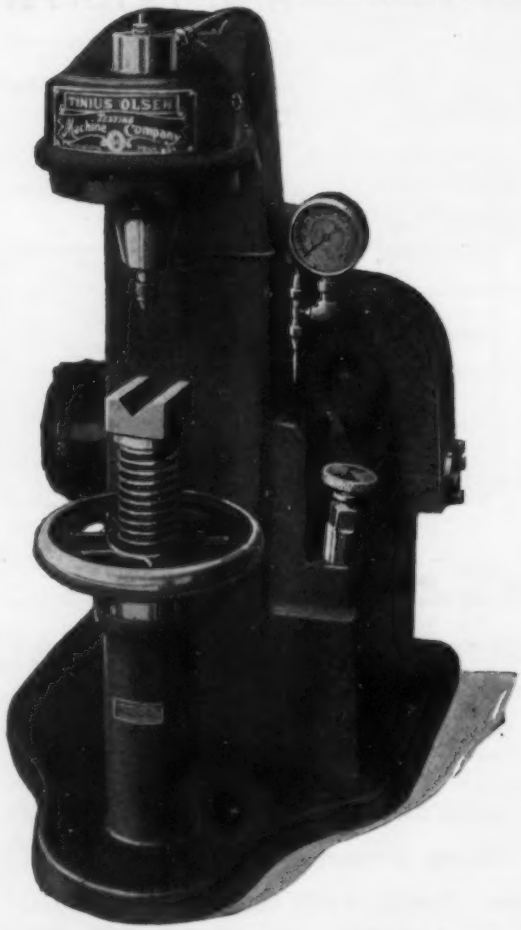

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"HOUGHTON'S LIQUID BATHS *for the* HEAT TREATMENT OF STEEL" is the title of a book, compiled by the Houghton Research Staff. It is a compilation of all of the best known practice in the use of liquid baths for steel and the information contained therein has been gathered from many sources and is the result of the widest practical experience. Therefore, there is one individual author of the work. Of course, some one person had to assume the responsibility of putting the information together, but even after that was done, two of the World's most noted physicists were engaged to criticize and correct the copy.

I personally had nothing whatsoever to do with preparing the original or corrected copy. In fact, the first I knew of the intention of the Houghton Research Staff to publish the book was when they brought the final corrected galley proof and requested that I should prepare the FOREWORD. Of course, my preparing the FOREWORD was not at all essential, but it is a habit our folks have, of insisting that I should in some way assume the responsibility of all their publications, by writing the FOREWORD, even though I have nothing whatsoever to do with the preparation of the original copy.

Naturally, before I would consent to subscribe my indorsement to the book, I satisfied myself that the contributors were reliable and the critics capable and fair and that the work as a whole was a capable first effort.

The Houghton Research Staff does not present "HOUGHTON'S LIQUID BATHS *for the* HEAT TREATMENT OF STEEL" with any thought that the book is perfect. The World is denied the benefit of much knowledge, not because the possessors of knowledge begrudge their knowledge to the Public, but because, knowing that their first contribution must be more or less faulty, they have not the courage to submit themselves to criticism.

"HOUGHTON'S LIQUID BATHS *for the* HEAT TREATMENT OF STEEL" is not published with any such fear of criticism, but rather for the express purpose of inviting criticism. Criticism will naturally lead to debate and debate in turn will lead to truth, which will naturally bring out errors and defects, which may be corrected in the next edition and thus as we correct each edition shall we arrive at final truth.

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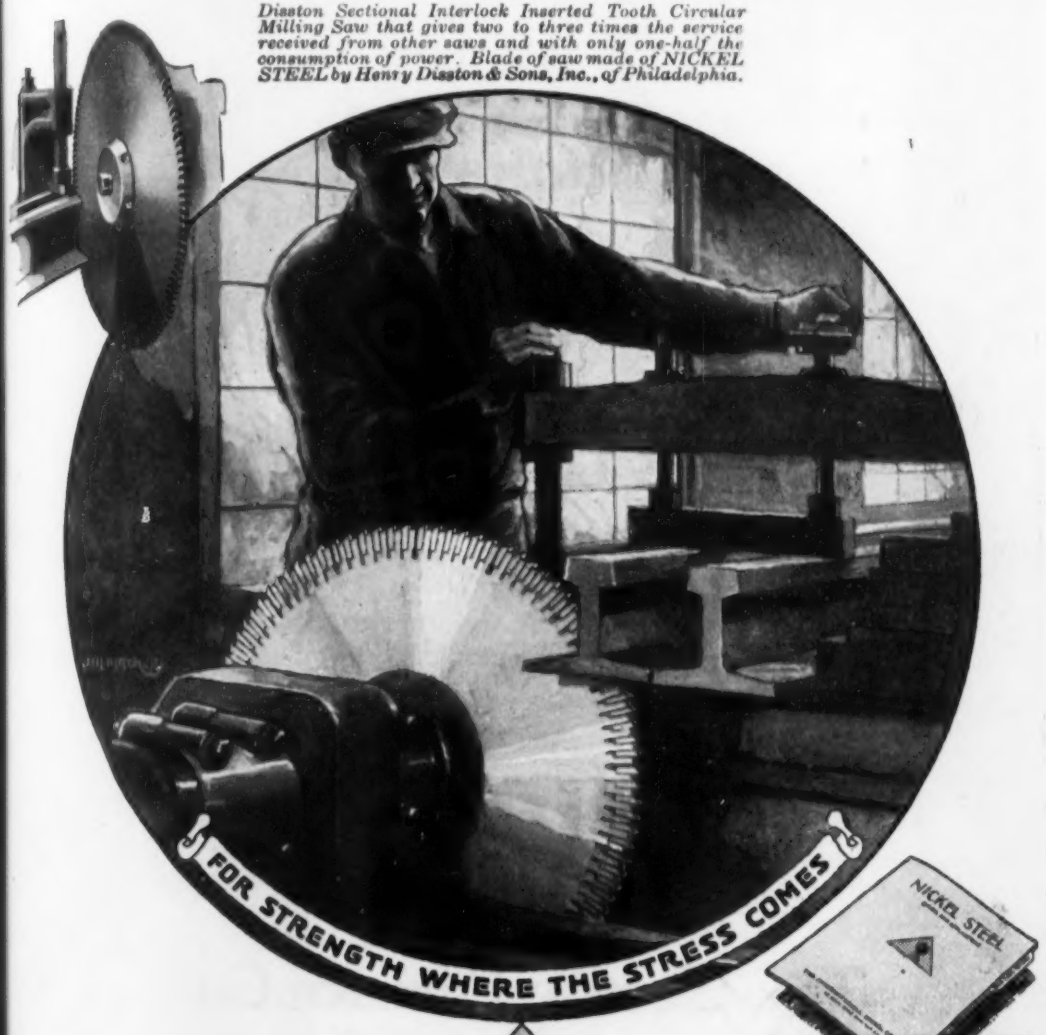

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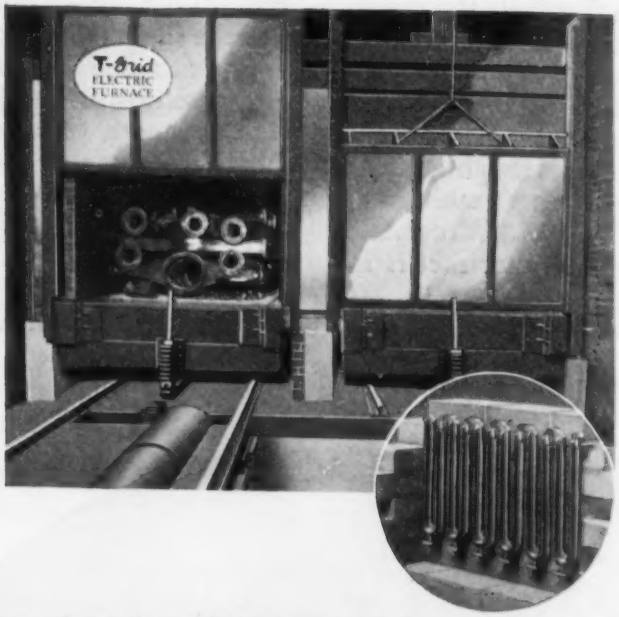

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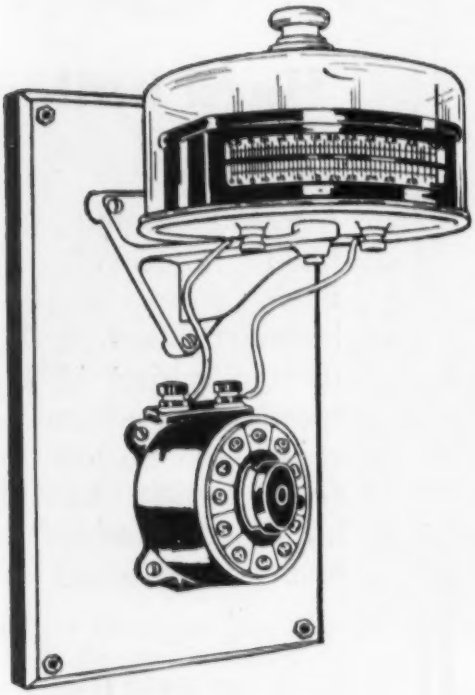

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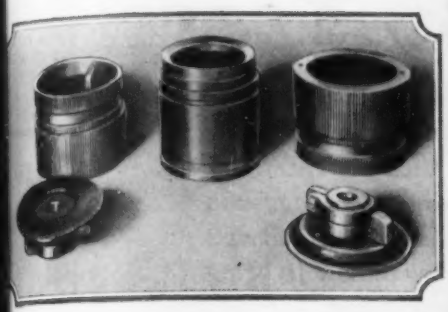

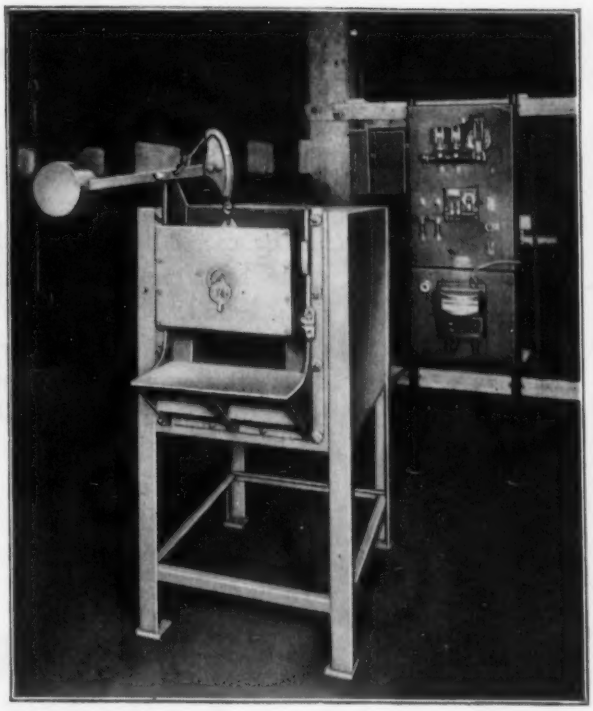

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Material and workmanship could not be improved, but the heat-treating could. So a G-E heat-treating furnace was installed.

The parts are now distinctive in their uniform high quality; rejects are unknown; heat-treating is clean and comfortable; and customer appreciation is rapidly mounting.

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ULTIMATELY ELECTRIC HEAT IN EVERY INDUSTRY

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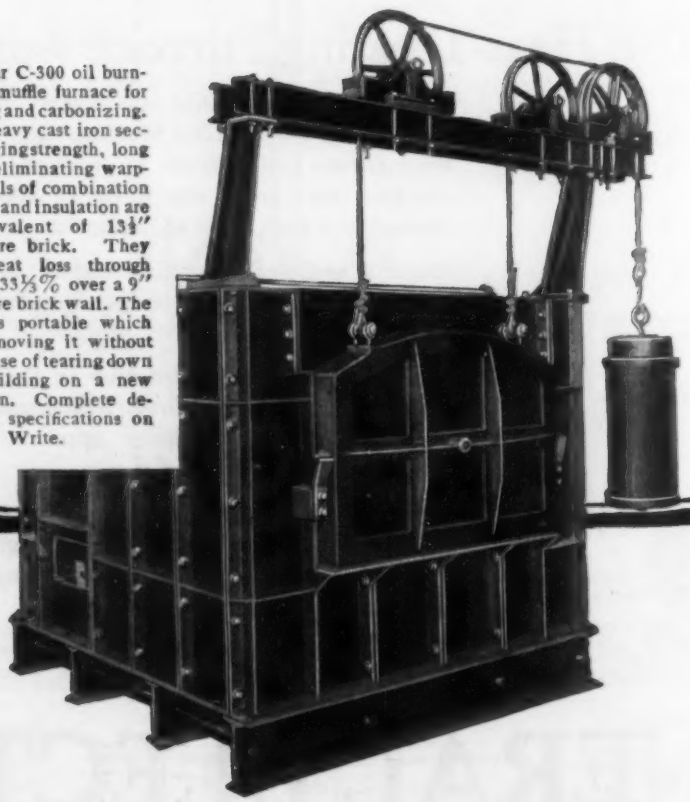

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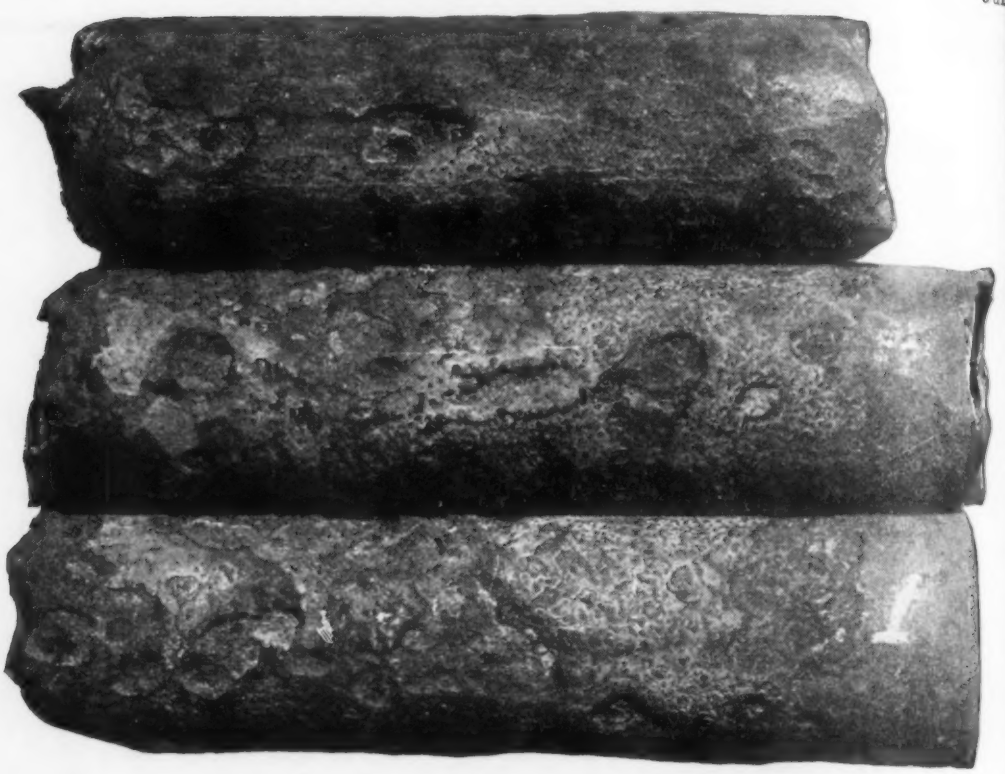

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NO-OX-ID stops pitting by reacting chemically. Pitting of iron and steel is localized corrosion between positive and negative areas in the metal. Moisture or damp soil conditions form the electrolyte through which this corrosive action is carried on. Before pitting is possible iron must go into solution. This solution takes place at the positive point or area; the iron in solution is converted to iron hydroxide and is deposited at the negative area. Progressive corrosion thus proceeds as long as moisture is present and as long as iron can go into solution.

NO-OX-ID properly applied, polarizes the reaction and stops the passage of iron into solution. This chemically prevents any further pitting action. In addition to this chemical protection **continuous** mechanical protection is afforded by the **elastic non-drying** film. No preparation which dries can give chemical protection and only **temporary** mechanical protection. Drying films cannot give intimate contact with metal. NO-OX-ID penetrates to stop deep seated corrosive action. NO-OX-ID does its work **under** the film chemically and **in** the film mechanically.

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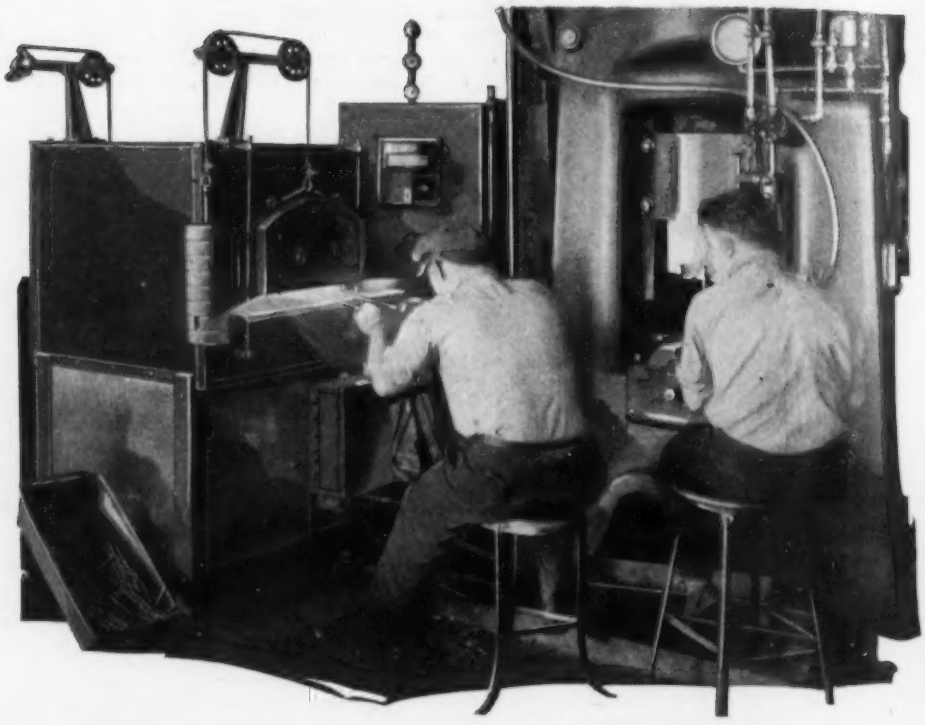

For Small Brass Forgings

A WELL known hardware manufacturer uses this Hoskins Electric Furnace for heating small brass blanks to a forging temperature.

One of the Executives of the company says: "Due to the fact that the blanks must be heated very close to the melting point, many blanks were ruined, because we could not control the temperature of our gas furnace closely enough.

"We installed the Hoskins Electric Furnace because it can be closely controlled, and because of absence of scale on the blanks, which is very important. The economy of operating this furnace is in the quality of work."

You will find other interesting facts in Catalog 50-S.

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Hoskins Electric Furnaces

Originators and Manufacturers of Chromel The Alloy that made Electric Heat Possible

Q=ALLOYS

STAND UP UNDER FIRE

THE

BOX BULLETIN

Published by

General Alloys Co.

Edited by
H. H. HARRIS

"You have not read Transactions until you've read The BOX BULLETIN"

GENERAL ALLOYS COMPANY

NAME IT YOURSELF

SOME of the Weary Readers of this blatant bleat wrote in the other da and said in effect "We know all about your dern alloy, we're all usi it,—can the sales talk and give us a laugh?" Not being able to fill th order from my scholarly and well ordered mind, I turned it over to H Chase, who took up his able pitchfork and wrote some hokum about Flori in the May issue. The protests are pouring in, so for a change I'll ret some smoking car scandal from the Toonerville trolley, not at the mome having an original thought.

The gentleman with the mauve spats: "Union labor has had two doggo stiff jolts lately, one when the British Lion dampened the miners' perad and recently when Dickey Byrd hihated the Esquimox on an open sh basis . . . . . yes, even the Arctic and Antarctic are highly unionize . . . . . Read your history,—you'll notice how these professional po hunters worked. One guy would go so far,—but not too far,—and th come home and write a book telling what a big guy he was. The next e plorer would go two hurdles farther than the last,—but not too far,—and on indefinitely. This proceeding has gone on for three generations. is rumored that Peary found the Pole accidently,—he lost his bearings and actually went there. Press associations have paid the big end of mo of these "expeditions," making fabulous profits selling the "story" to t papers. Pole hunting has been highly unionized, in fact you had to hav union card to sit in on the game. Then along came Commander Richa Byrd, of the U. S. Navy. Dick was strictly non-union, in fact he w scarcely an apprentice. Edsel Ford, and John D. Jr., both non-uni

BOX BULLETIN SUPPLEMENT PAGE 111

backed him. Dick **went** to the Pole, a round trip in 15 hours, without knowing about the union rules. Extremely careless of Richard! The Pole is now on an open shop basis."

The Klux und Suits Salesman and his Boy Friend: "Say Abe:—I hoid dat your brudder made fifty tousand dollar in Miamy in der real estate business." B. F. "Dat vos only bartly korrekt, Benny,—dat vosn't my brudder, dat vos my kosin Jake,—und,—it vosnt in Floridy,—it vos in Californy,—und,—it vosnt real estate, it vos delicatessen,—und,—it vosnt fifty tousand dollar,—it vos five tousand dollar,—und,—he didnt make it, he lost it,—und,—it vassent his money,—it vos my money,—Oy, Oy, Oy,—OY!"

The Doctor: "If I live twenty years longer, I expect to live another hundred,—the progress of medical science promises the solution of longevity, and the Fountain of Youth may be in every hospital in the land."

The Metallurgist, (in answer): "Yes, I'll grant that the medical profession has done much to increase the span of life, decrease infant mortality, and patch up the human race, but you're naturefakin' Doc, and the "Improvements" you effect in one generation, the weak impotent individuals "patched up" and kept alive by medical skill, will have offspring of inferior physical and mental ability unfit to cope with life" . . . . . "Nature in her wisdom destroys the unfit, thus keeping up the stamina of the breed. The Pilgrim fathers, the warriors of old, were "He" men primarily because they were good animals, sound physically and mentally; they were the "fittest" who survived. The "Bad Eggs" and the broken ones are sorted from the sound by the hand of Providence. Putting them back into the basket, with minor repairs, but temporarily defeats the intent of nature, for the lot is often contaminated. The "Monkey Gland" Centurians will doubtless rear half wit progeny,—or maybe 7/8 (these won't buy Q-Alloys)

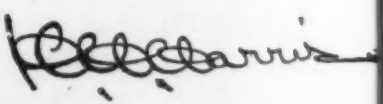
The Statistician, (with a philosophy): "The Power developed in the combustion of one pound of coal is equal to 11,580,000 foot pounds. We can yet utilize only about 1,500,000 foot pounds. This is the amount of energy exerted by an average man in a day's work. Hence 300 pounds will represent a man's labor for a year. The world's annual coal production exceeds 500,000,000 tons. If half of this coal goes for work we have approximately 1,600,000,000 man-powers that are producers but not consumers. Such is our "Fuel Power." The World has approximately 1,600,000,000 people; a wealth of approximately $357,000,000,000, which represents **dead men's work,** and fuel power equal in work to our whole

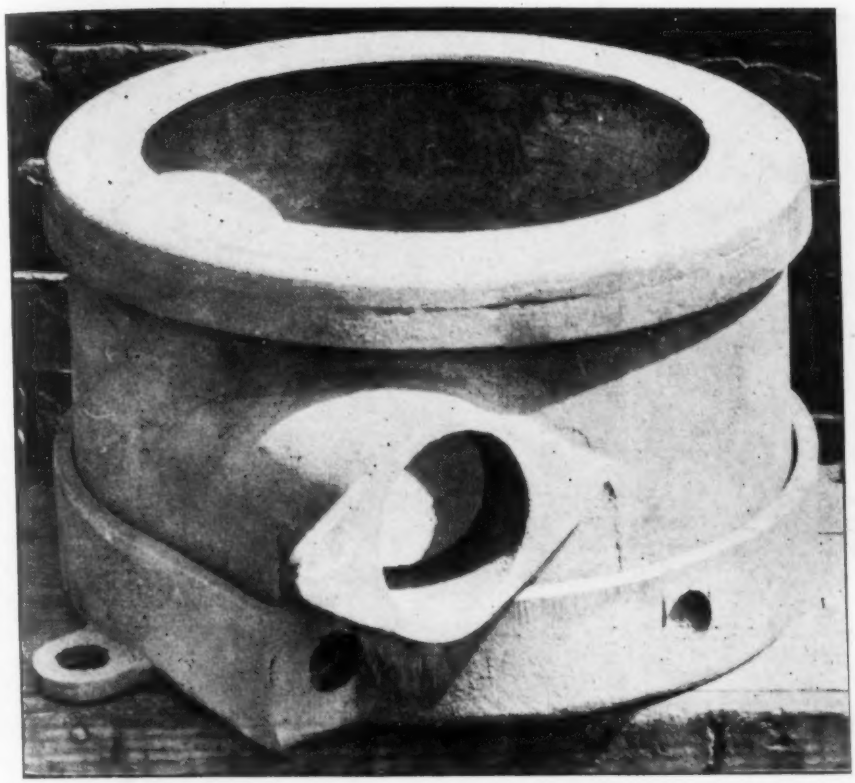
living population applied annually. For simplicity say $35.70 is the average living expense per annum for each of the worlds population, we will have: (1). 1,600,000,000 living men. (2). 10,000,000,000 living man-powers of the dead (wealth). (3). 1,600,000,000 fuel man-powers. So we see the world is populated today by three different populations, all of them dynamic and active. Here we have a problem of enormous magnitude. To serve 1,600,000,000 living men, we have 11,600,000,000 dead man-powers and all the reserve of fuel powers,—or SEVEN SERVANTS TO EACH LIVING MAN, WOMAN, AND CHILD. It looks like the millennium, doesn't it?"

THE ENGLISHMAN: He didn't say a thing, but sat there fingering his monocle. "What's that guy wear the third eye for?" asked the brakeman of the porter. "Well suh ah reckons mebbe he wear dat air winshield so as he wont see mor'n he can understan' at a time, suh," observed the porter.

Then we all got off at St. Thomas for some Canadian 4.4 beer that should make seven generations of honest brewerymen turn over in their graves. Returning to the car to resume our journey, the Englishman seemed in a more affable mood, he was reading a headline in a Detroit paper about our immigration troubles, and observed cheerfully "Hi si bys, you himaricans ave your troubles, dontcha know, maintainin' this ere 'Meltin Pot' with 57 varieties. Over 'ome we 'ave our troubles with only three races,—The Scotch who pray on their knees and their neighbors, the Irish who don't know what they want, but are willing to die for it, and the English who are self made men and worship their Creator." Just then another Englishman who had entered socked him with a beer bottle, and we sought our berths in the scuffle. The Monocle will be exhibited at the A. S. S. T. Show in Chi.

Maybe there's a laugh or a thought, in the above, if you laugh and think, or maybe this high pressure work getting out the best alloys possible is turning me a bit goofey, anyway, here's "Exhibit A" and "What ever you say may be used against you."



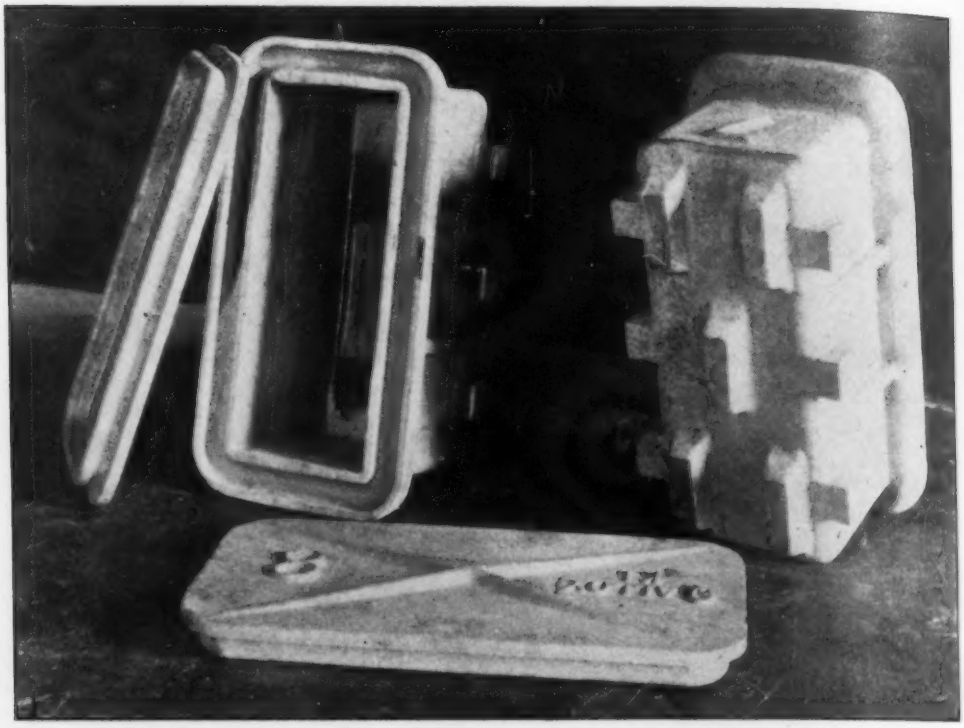


OIL BURNERS

RECENTLY we attended a convention of oil burner manufacturers at Detroit, accidentally dropping into their exhibit at the Book-Cadillac. We did not solicit business, but we did notice that there were a number of domestic oil burners shown that spell G-R-I-E-F, to the unfortunate people who buy them because of cheap inferior alloy fire pots and alloy baffles supplied as standard equipment. Some of these "Alloys" were merely silicon cast iron, others were undependable varieties of high chromium steel, others the high iron variety of "Cheap" alloys.

The steel treater has learned the costly lesson of buying "Just as good for half the price" substitutes for Q-Alloys. The vitreous enameling industries are just cutting their eye teeth, (the Q-Alloy pointbar burning rack business has increased TWELVE HUNDRED PER CENT in twelve months). We didn't solicit burning rack business, until Q-Alloy cast racks had outlasted the best rolled and forged pin racks of our largest competitor THREE-TO-ONE. Within this year we will have 80 per cent of the alloy burning rack business in the world.

We are not actively soliciting fire-pot business,—But,—if you buy a domestic oil burner, keep both eyes on the fire-pot, and demand a two year' written guarantee,—or a Q-Alloy fire-pot, for we do not want any steel treater stung again on "Cheap" alloys.

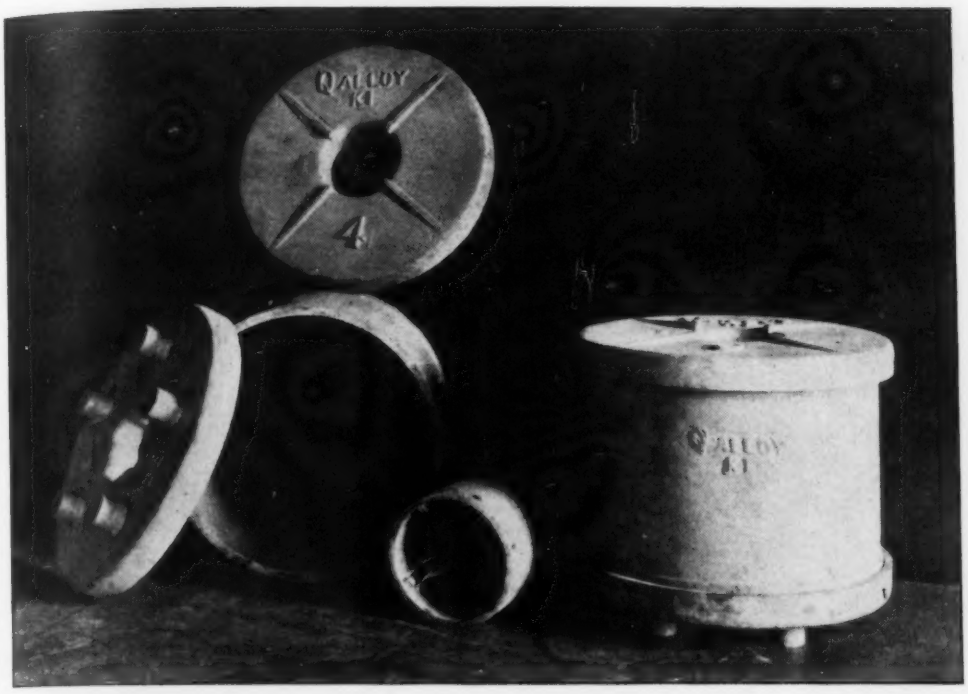


Keyed to the Rails

THESE boxes are almost identical with a large order supplied in 1920, and still running. The only change is in the method of keying them to the rails in the continuous furnace. This style of "tongue and groove" seal, providing for pressure sealing originally is now being used without luting of any kind and is functioning "100 per cent." "Soft spots are unknown with our Q-Alloy boxes," the superintendent advises.

The cored-out lugs shown are specially chilled to remove porosity, and are so strong that a case of broken lugs is unknown in this plant. The customer using these boxes can buy other alloy boxes far "cheaper" elsewhere. In fact they have tried it on several occasions. That fact alone has helped account for over THIRTY-FOUR REPEAT ORDERS FROM THIS CUSTOMER.

If you need rails and boxes that work together harmoniously,—in fact if you would preserve the harmony of your heat-treat, specify the best. "The top of the ladder is never crowded",—in this case it is ISOLATED, for Q-Alloy quality stands ALONE.



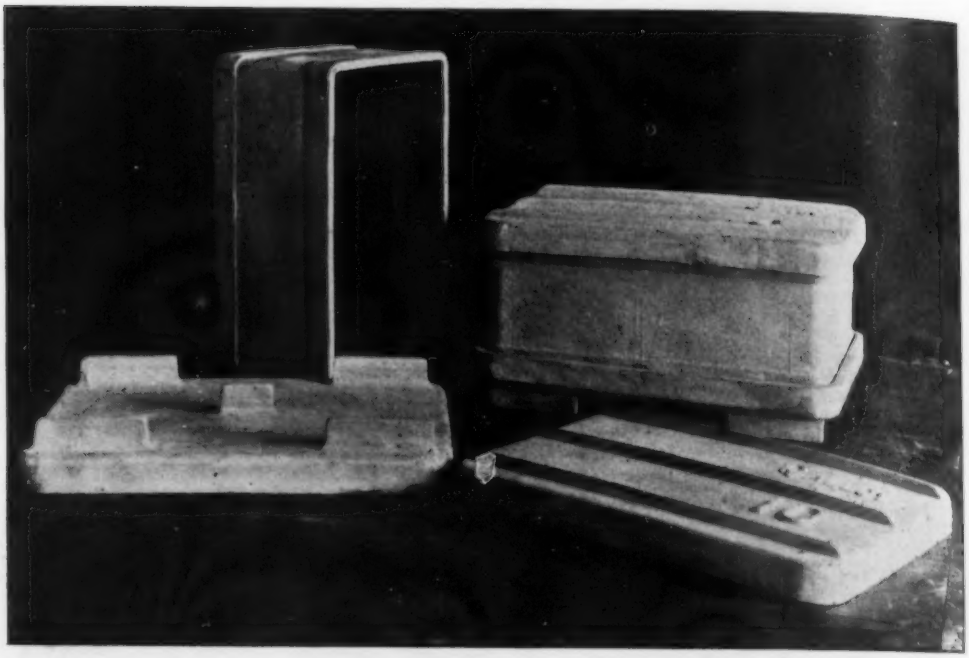
MACHINE PRECISION IN SAND

THE largest manufacturer in the world of automobiles costing over four thousand dollars has some original and very definite ideas about packing pots,—not only carefully, but accurately.

Ordinary flue-type pot designs would not meet their requirements. Then our engineering department was consulted, and the above pot is the result. Patents are applied for on this interlocking construction,—but patents, or no patents, there is no danger of successful imitation.

Foundry practice, the finest yet achieved in heat-resisting alloys, has made these "interchangeable, interlocking unit" pots. Note how the chimney, or "flue" is removable by a simple movement, yet maintains alignment during use.

If you want better results, and special equipment designed to fit your problems will help, it will pay you to consult us,—we may find facts and figures in our extensive experience to help you,—maybe we will both learn in whipping your problems together. WHY WAIT?



Three Piece Boxes May Do You No Good

AND then, again, they might. In some plants they would be a nuisance, unwarranted, and unwanted,—but somebody wanted these, and they were designed to meet a special requirement.

These boxes can be dumped, and reloaded while hot, on the switchback of a counterflow furnace, and possess certain definite advantages. These have been carefully tabulated from use, and the whole story of three-piece boxes is available for the benefit of the industry.

Certain features of these new type boxes will be fully covered by patents, and backed by a maker capable of defending them.

NO PATENTED FEATURES OF ANY Q-ALLOY DEVELOPMENTS WILL EVER BE ADDED TO THE PRICE BUT ARE INCLUDED AS A PART OF THE Q-Alloy service.

DO TON-MILES COUNT?

THIS innocent looking ANNEALING BOX posed for its photo en route to one of the largest ball bearing plants, where it will be called upon to equal the results of its predecessors,—pay dividends to its owner,—and incidentally save enough TON-MILES to set up a substantial CREDIT.

Translate Ton-Miles into Foot-Pounds, if you wish, and then figure the saving in handling from 20 to 40% less weight, every time a box is moved,—into the furnace, out of the furnace, and around the heat-treat.

Then figure the FUEL SAVING,—and finally,—the CASH REBATE FOR SCRAP.

Q-ALLOYS

Most Economical and Efficient Materials

For CARBONIZING BOXES
ANNEALING BOXES
CYANIDE AND LEAD POTS
FURNACE PLATES
MUFFLES AND RACKS
TUBES AND RETORTS
CONVEYOR FURNACES
GLASS ROLLS AND DIES
ANY PARTS

operating between 1000° F. and 2200° F.

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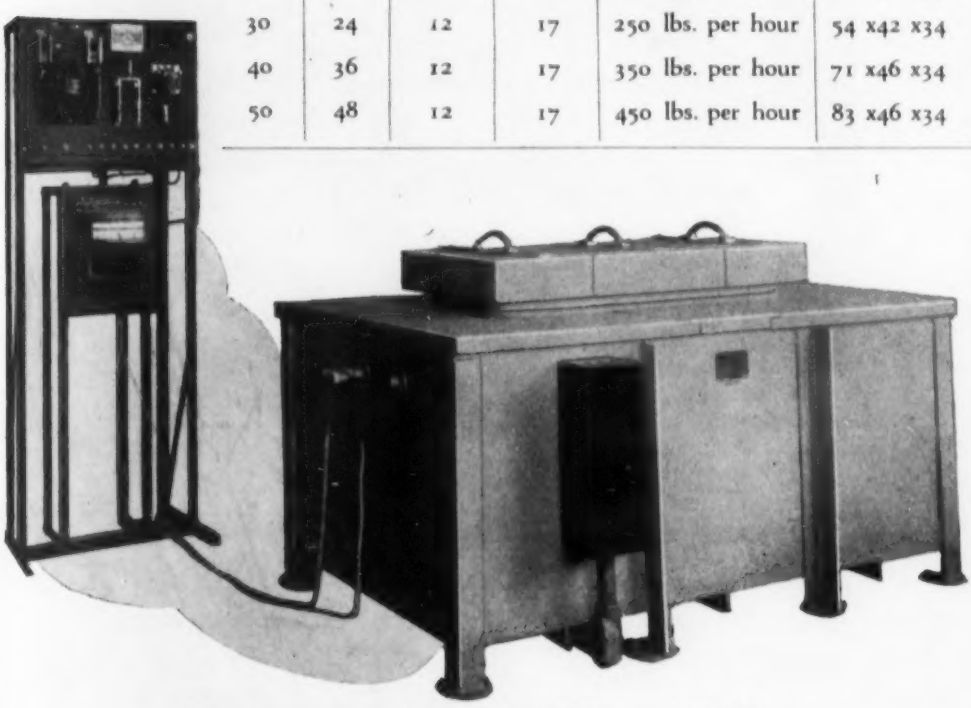
When writing to General Alloys Company, please mention TRANSACTIONS

AMERICAN Electric
RECTANGULAR POT FURNACES

STOCK SIZES

Size of Pot					
K.W.	*Lght.*	*Wdth.*	*Depth.*	*Capacity*	*Outside Dimension*
20	18"	12"	17"	150 lbs. per hour	48"x42"x34"
30	24	12	17	250 lbs. per hour	54 x42 x34
40	36	12	17	350 lbs. per hour	71 x46 x34
50	48	12	17	450 lbs. per hour	83 x46 x34



TEMPERATURE RANGE, 400°F. to 1650°F.

For lead, cyanide or salt hardening.
White metal and aluminum melting.

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BOSTON, MASSACHUSETTS

112 YEARS
of
FURNACE EXPERIENCE

Drafting Dept. of our Milwaukee Plant

112 years represents the aggregate time spent in actual furnace work by our engineers. We have been building electric furnaces exclusively since 1912.

This is the first of a series of advertisements describing our plant and organization

HEVI DUTY ELECTRIC CO.

MILWAUKEE, WIS.

(Formerly Electric Heating Apparatus Co., Newark, N. J.)

NEW YORK **BUFFALO** **CLEVELAND** **CHICAGO**

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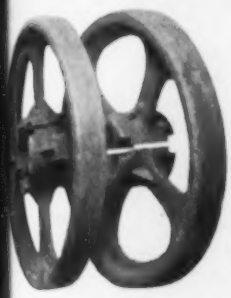
FAHRITE

Heat-Resisting Alloy Castings



Discs used in continuous Annealing Furnace

$8000 Installation of FAHRITE DISCS still going after 2 years

Temperature 1900° to 1950° F.

Performance tells the story →

Highly economical for
- Carbonizing Boxes
- Annealing Boxes and Equipment
- Tube Supports
- Furnace Hearths
- Discs, Chains, Rails, etc., for Continuous Furnace
- Enamel Burning Equipment
- Retorts
- All parts operating over 1000° Fahr.

THE FALCON STEEL COMPANY

NILES, OHIO
May 6, 1926.

E. L. McNamara
Purchasing Agent

Ohio Steel Foundry Company,
Springfield, Ohio.

Gentlemen:-

Answering your letter of May 3rd, we wish to inform you that the "Fahrite" furnace discs we purchased from you in January 1924 are still in use and in good condition so far as can be determined.

As you know, these are used in our continuous open annealing furnaces. On one furnace, they are subjected to a temperature ranging from 1900 to 1960 degrees Fahrenheit. On the other furnace, a lower temperature is used but we can notice no difference in the condition of the discs in the two furnaces. We might add that we have not used these furnaces continuously since January 1924, but we feel that should we have done so, our discs would still be in very good condition.

Our opinion is that a proper proportion of the materials used in this alloy is the real solution for a heat resisting alloy in this type of furnace. However, we feel also that the disc design must be right to get the best results.

Very truly yours,
THE FALCON STEEL COMPANY
R. H. Grove
Chief Engineer

RHG:T

THE OHIO STEEL FOUNDRY CO.

Springfield, Ohio

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Plants in

Springfield
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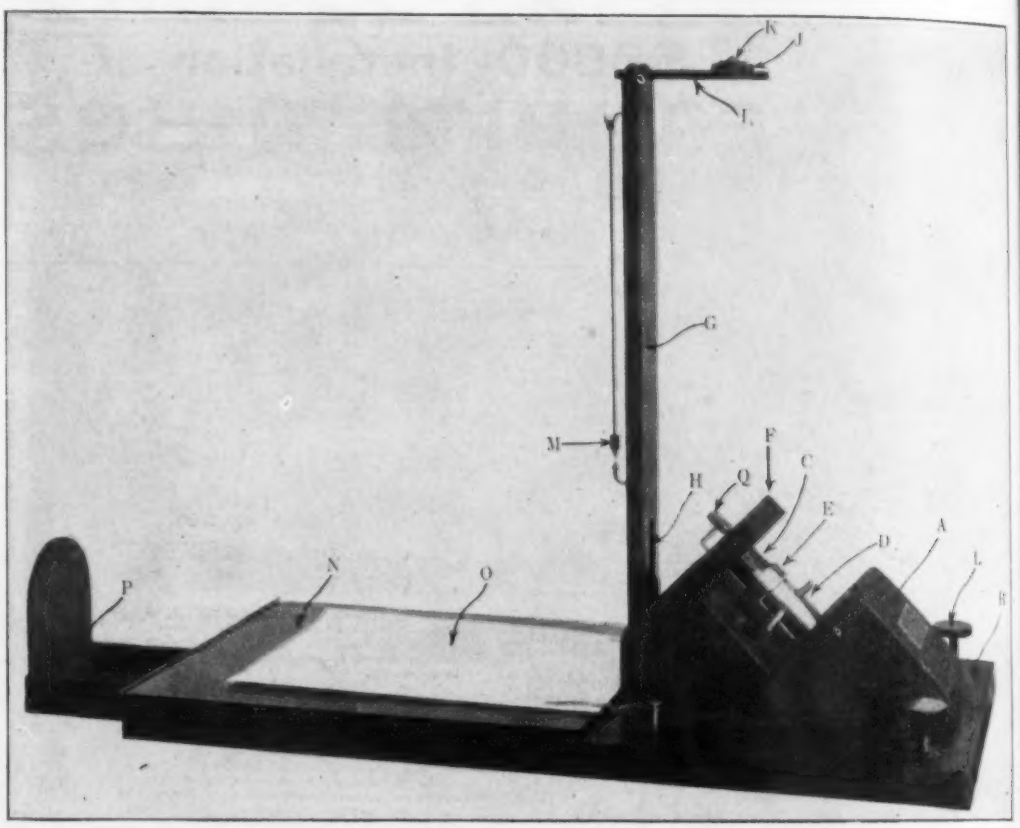
SAUVEUR DUROMETER



THE instrument pictured above is the newest development in hardness testing apparatus both for metals and other hard substances. It was developed and perfected by Dr. Albert Sauveur of Harvard University.

It has a wide field of application—is accurate, easy to manipulate, and thoroughly dependable.

Price $95 F. O. B. Boston, Mass.

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Show Your Colors

ALL MEMBERS of the A. S. S. T. should make a practice of wearing the Society emblem. It is neat and inconspicuous and immediately conveys the information that the wearer is a progressive individual and a member of a live, wide awake organization. The pin is in black and gold as shown above, with safety fastener, and will be mailed, post paid upon receipt of $1.00.

AMERICAN SOCIETY FOR STEEL TREATING
4600 Prospect Ave. **Cleveland, O.**

No Initiation Fee

Application for Membership in the

American Society for Steel Treating

4600 Prospect Ave., Cleveland, Ohio

(See opposite page for Classification and rate for dues.)

I hereby make application for (Member Junior Associate Sustaining) membership in the Society, and agree, if elected, that I will be governed by the Constitution, By-Laws and Rules of the Society as long as I continue a member. I furthermore agree to promote the objects of the Society so far as it shall be in my power. $5.00 of my dues is for one year's subscription to The Transactions of the American Society for Steel Treating.

The annual dues for membership and the annual contribution for Sustaining members shall be as follows:

For Member	$10.00
For Associate	15.00
For Junior	2.50
For Sustaining Member, not less than	25.00

*Date*_____

Name _____
(Please print)

Firm Name _____

City _____ *State* _____

*State fully what your firm manufactures or deals in*_____

_____

*Are you in the Sales Department?*_____

*Title or Position with Said Firm*_____

*To which Chapter do you wish to belong?*_____

*To what address do you wish your mail from this Society sent?*_____

_____

Endorsed by _____ Member

If candidate does not know any member of the Society, a reference will be satisfactory.

Reference _____

All members in good standing will receive the Society's publications, which contain papers presented at the chapter, sectional and annual meetings.

SERVICE FOR MEMBERS

The Library Bureau of the American Society for Steel Treating is operated to give to the members quickly, reliably and at the minimum expense the following service:

1. A complete copy of the magazine article referred to in any periodical you may be reading.
2. A Translation of foreign articles that would help you with your work.
3. A list of references to books and articles on any metallurgical subject.
4. Informing the members of new articles of interest to them as an engineer.
5. Patent Reviews.

The Library Bureau makes the entire field of literature available to every member, distance is eliminated, for it will copy the desired information and send it to you. It also helps the busy man by supplying information without any expenditure of his time. The charge for this personal work is merely its cost.

Through the courtesy of Nelson Littell, we have secured an additional library service for members of the A. S. S. T. This service comprises the selecting and supplying of copies of current patents, on specified subjects, as they are issued by the Patent Office.

Mr. Littell will review the Official Gazette each week, selecting those patents on subjects desired by individual subscribers, and order separate copies mailed directly to them from the U. S. Patent Office. Subscribers may specify the field of patents which would be of interest, or they may supply a list of their products and manufacturing processes whereby Mr. Littell could judge as to what current patents would be of interest to them.

The cost for this service is $10.00 per year, plus 10 cents per copy for each copy of a patent furnished.

The Library Service does not obtain any profit from the work, but does this to make the information contained in the large libraries with which it has connection available to every member. The rates are as follows:

Photo Print Copies of articles, drawings, etc., 25c per 10x14-inch sheets.
Searches, abstracts, etc., $2.00 an hour.
Translation, $6.00 per thousand words for French or German; $7.50 and upwards for other languages.
Reference card service, giving reference to current magazine articles, $10.00 a year in advance, and 5c for each card mailed.

Members desiring to avail themselves of this service should address Library Bureau, American Society for Steel Treating, 4600 Prospect Ave., Cleveland, Ohio.

CLASSIFICATION OF MEMBERSHIP

American Society for Steel Treating

The following paragraphs from the Constitution should enable you to properly fill the application form on opposite page:

Art. IV. Section 1. (c) "A MEMBER shall be a person, twenty-one years of age or over, who is engaged in work related to the manufacture or treatment of metals, or the arts connected therewith, and who is not a member of the sales department of any organization which manufactures or deals in materials, supplies or equipment of any nature whatsoever used in such arts."
Dues $10.00 per annum.

(d) "An ASSOCIATE shall be a person, at least twenty-one years of age, who is engaged in work related to the manufacture or treatment of metals, or the arts connected therewith, and who is a member of the sales department of an organization which manufactures or deals in materials, supplies or equipment used in such arts."
Dues $15.00 per annum.

(e) "SUSTAINING MEMBERS shall be those persons, firms or corporations, who, because of exceptional interest in the work of the Society, contribute the annual dues of Sustaining Members as hereinafter set forth."

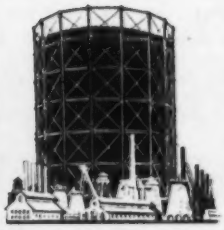
Membership in this class will be awarded to those who contribute not less than $25.00 yearly, and will be acknowledged by printing the name of the donor in each issue of the Society's Transactions under the caption "Sustaining Members."

Art. IV. Sec. 1. (f) "A JUNIOR shall be a person interested in, or engaged in, work related to the manufacture or treatment of metals or the arts connected therewith, who is either (1) in attendance as a student at some institution of learning, or (2) under twenty-one years of age."

Dues $2.50 per annum. This fee includes subscription to The Transactions and Data Sheets.

All dues are payable immediately upon notification of election to membership and are for one year from date of said election. Following payments are due upon same date each year.

If a member desires, his dues may be paid in two equal installments.



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342 Madison Avenue :: New York City

YOU CAN DO IT BETTER WITH ·· GAS ··

Heat Treating Problems

NO. 1

The Case of the brittle Spring

A certain manufacturer ordered a lot of springs formed as above, the heat treating to be done at the manufacturer's own plant. The steel analysis specification indicated hardening at 1450° F. and tempering at 500° F. The springs were put through and turned out O. K.

A re-order was placed with the same specifications. But, the same heat treatment as used in the first lot resulted in making the new springs too brittle. Urgent need of the springs precluded their return, and made it necessary to heat treat them again. Therefore, experiment with different temperatures became necessary to discover proper heat treatment.

BROWN PYROMETER equipment made solution of the problem a simple matter. The new lot of springs was found to require a tempering temperature of 650° F. Brown Pyrometers made it easy to obtain perfect results without guessing and with minimum experimenting.

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EXTRA REFINED
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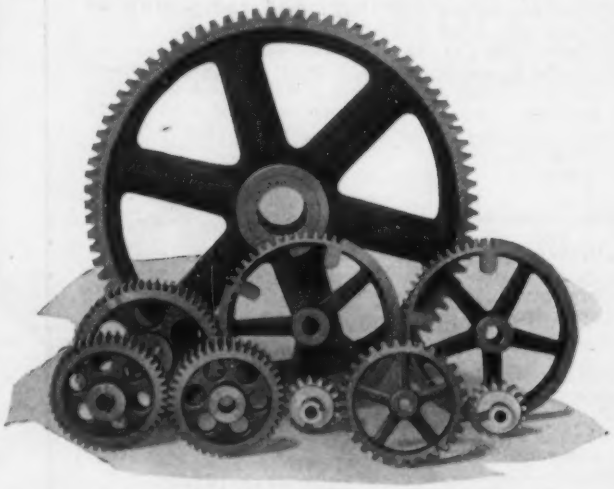

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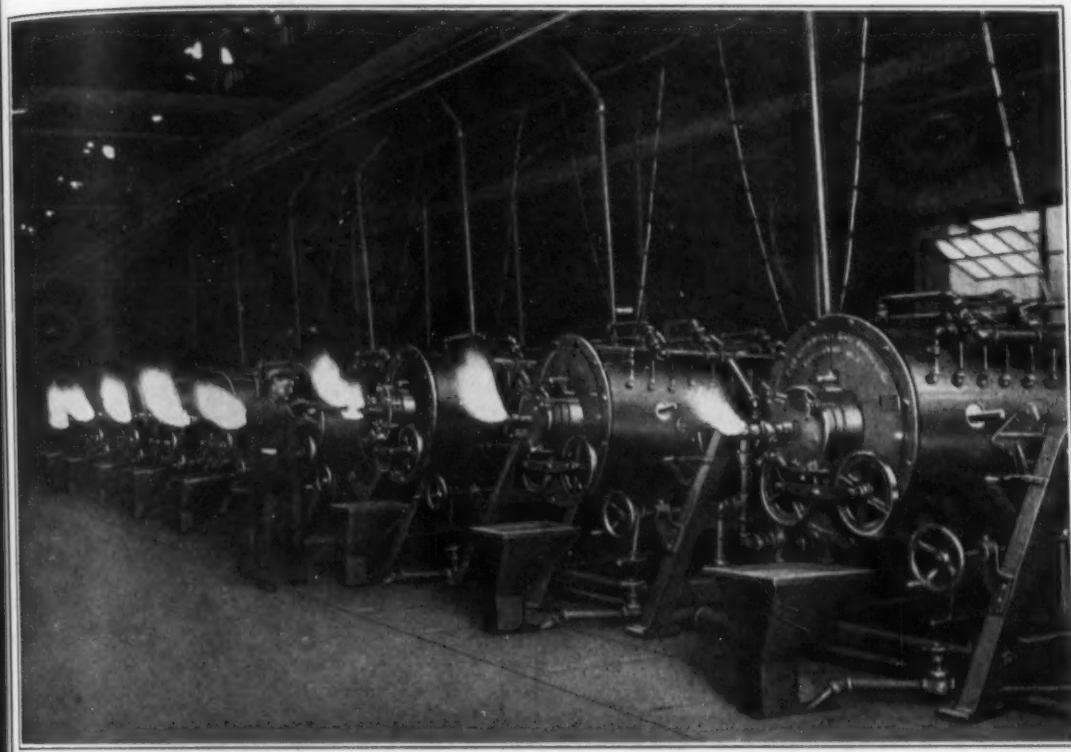
Part of a battery of 23

"AMERICAN" Rotary Gas Carbonizing Machines

Used in carbonizing Timken Roller Bearings



At the Timken Roller Bearing Company, Canton, Ohio, home of the universally known Roller Bearing, a battery of 23 Gas-Fired "American" Rotary Gas Carbonizing Machines are in operation. These machines are used in carburizing parts for this famous roller bearing because they deliver quality results—quickly—accurately—economically.

The work is uniformly heated in the slowly rotating retorts of these machines and is constantly and uniformly exposed to a carbon-charged atmosphere which insures uniform treatment and carbon penetration.

Bulletin T-12 describes these machines in detail.

American Gas Furnace Co.

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CLEAN — UNIFORM

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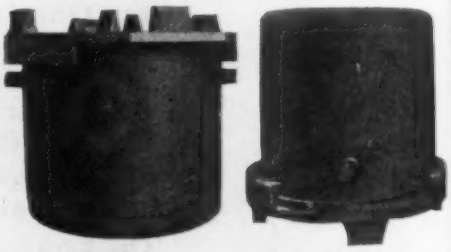
CARBURIZING BOXES
"The Cost Cutting Box"



Loaded Inverted for furnace.

The Original Inverted Box.
Retention of Gases Builds Pressure and Gives Deeper and More Uniform Penetration.
Saves Material and Prevents Scaling and Oxidation.
No Claying or Screening.
Gives Equal Depth of Case in Less Time.
Every Layer Carburized Uniformly.

YOU "WIL-CAN" OTHER TYPES AFTER A TRIAL

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BRAND STEELS

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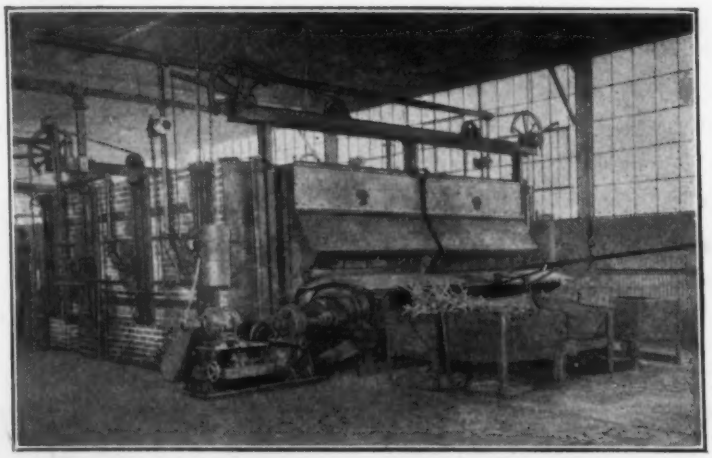
ELECTRIC AND FUEL FURNACES

FOR HEAT-TREATING

AUTOMATIC, SEMI-AUTOMATIC AND STATIONARY TYPES



AUTOMATIC HEAT-TREATING FURNACE

FURNACES and fuels should be selected for the useful service they can render when properly employed under specific conditions, and with due regard to their form as well as price. Each should be selected on its merits. Their use is but a means to an end, **the economic value of which is measured by the resulting quality and cost of the finished product or service,** and not by any one phase of their performance.

We are free from prejudice or preference in the matter of fuel or electricity, or type of furnace equipment, as our aim is to deal with each case on its merits.

Bulletin 234-C illustrates methods of heating and handling and furnaces employed in a great variety of heat-treating operations.
Write nearest office for a Copy

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answered in this FREE book on steel treating problems

IF you are interested in proper heat treating temperatures and operations, the most approved practice in steel treating, and the quenching and cooling equipment that has given the most satisfactory results in hundreds of progressive plants such as Ford, General Motors, Hyatt, Packard, and Ingersoll-Rand, write to The Griscom-Russell Co., Dept. G. 285 Madison Ave., New York, for free copy of their treatise on The Cooling of Quenching Oil in the Heat Treatment of Steel.

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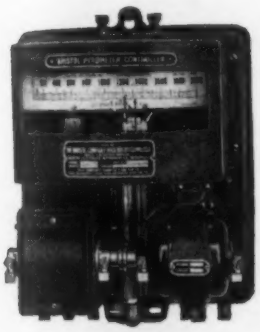
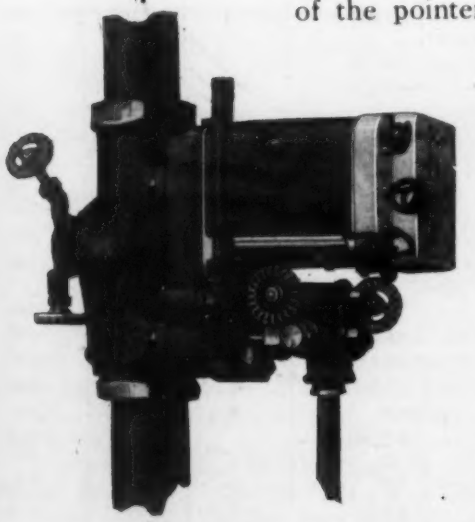


Closer Temperature Control Is Now Possible

For heat treating jobs where exact temperature control is imperative, Bristol's New Pyrometer Controller will prove equal to the test.

This instrument is the result of several years of experimental work and trial under actual operating conditions in the field and incorporates many distinctive features.

The wide open, 7 inch scale; the large magnet, which gives plenty of power for the movement of the pointer; and the safety adjustment mechanism for setting the index pointer, are features to be found only in Bristol's.



This Pyrometer Regulator is extremely accurate in operation and will control temperatures more closely than can be read on a full scale instrument.

These features plus rugged construction make this instrument the ideal for use in shop practice.

The Bristol Company *Waterbury, Connecticut*

FOR 36 YEARS — Ask Any Technical Engineer — MAKERS OF

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Send all orders to A. S. S. T., 4600 PROSPECT AVE., CLEVELAND, O.

	Page No.	No. Sheets	Cost to Members	Cost to Non-Members
Nitrogen in Steel	A3-4	1	$0.05	$0.10
Melting Points of Chemical Elements Fusing Points of Seger Cones	A5 A6	1	.05	.10
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Decimal and Metric Equivalents of Parts of an Inch	A7-10	2	.10	.20
Specific Heat of Air	A11-14	2	.10	.20
Weights of Steel Bars Wire Gauges	A15-22	4	.20	.40
Temperature Conversion Table	A23 and 24	1	.05	.10
Iron-Carbon Diagram	A25-38	7	.35	.70
Mass Influence in Heat Treatment	A39-42 Incl.	2	.10	.20
Interconversion Table for Units of Energy, Volume and Weight	A43-44	1	.05	.10
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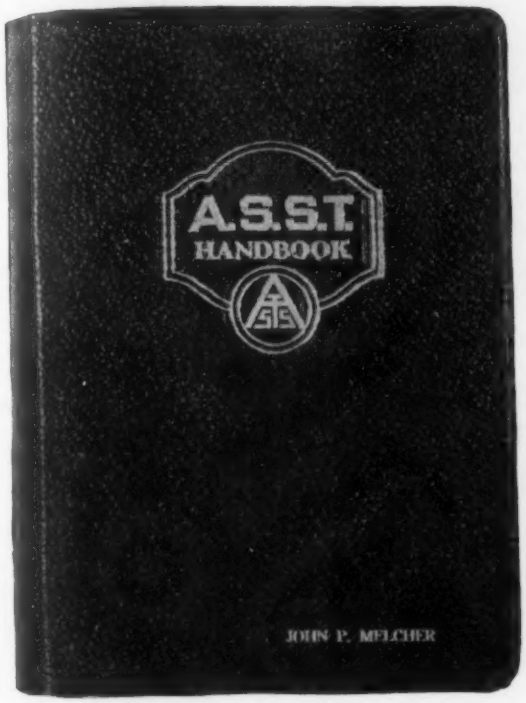

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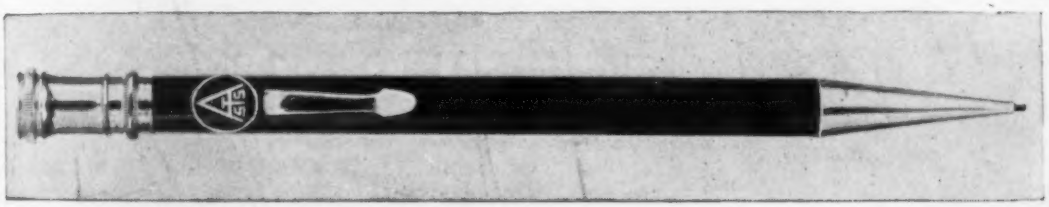

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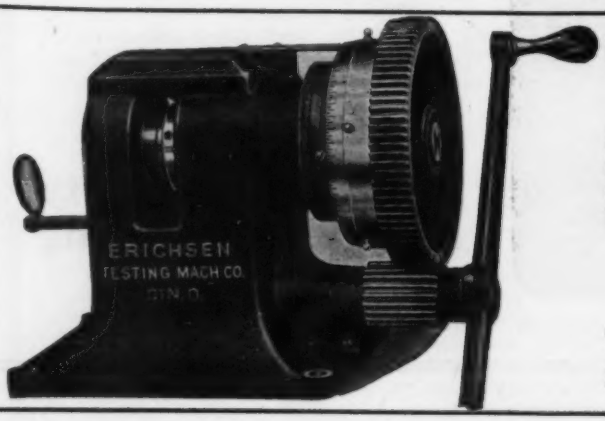

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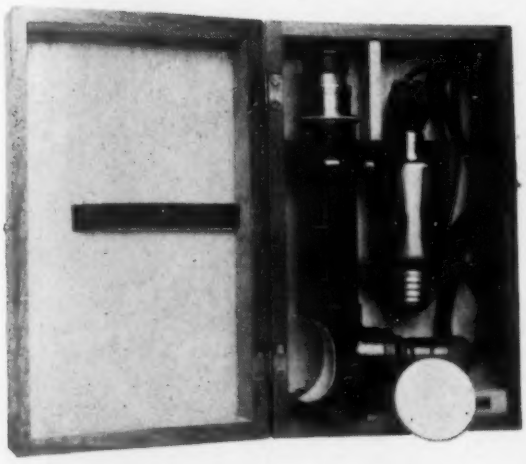

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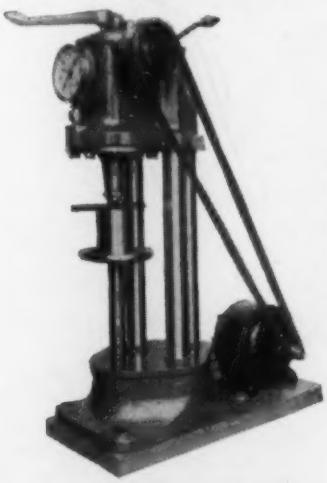

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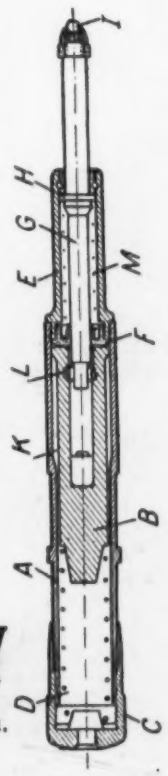

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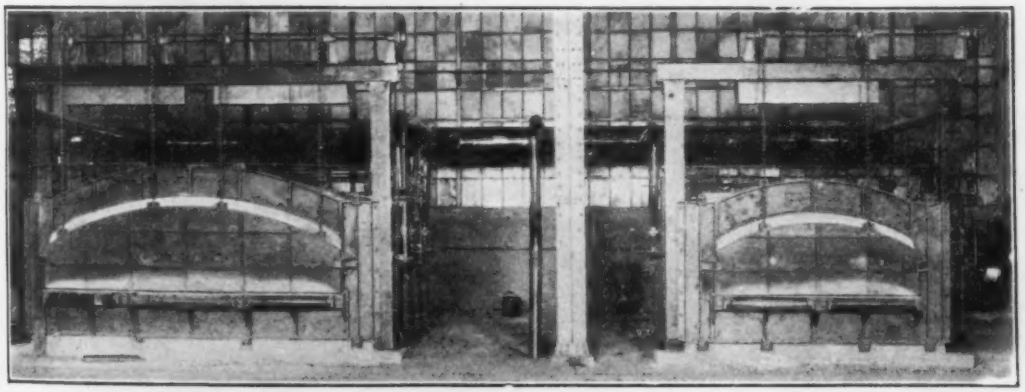

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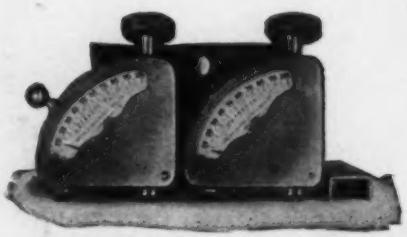

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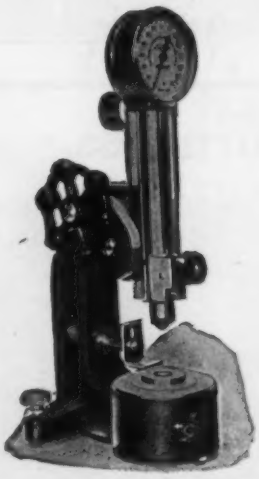

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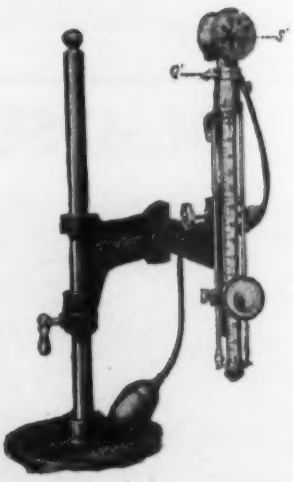

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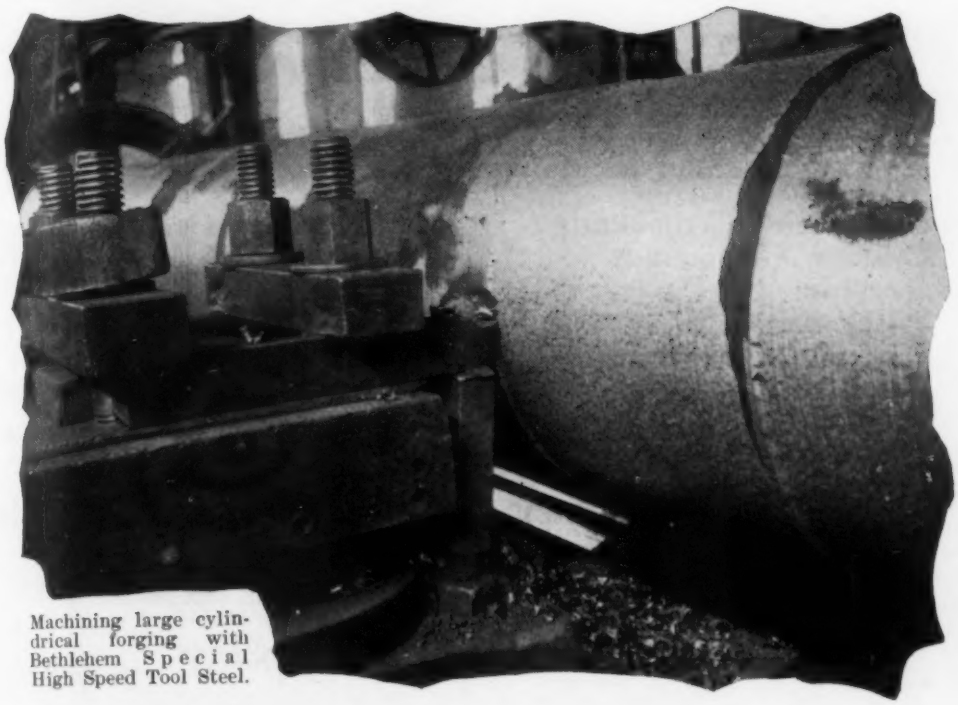

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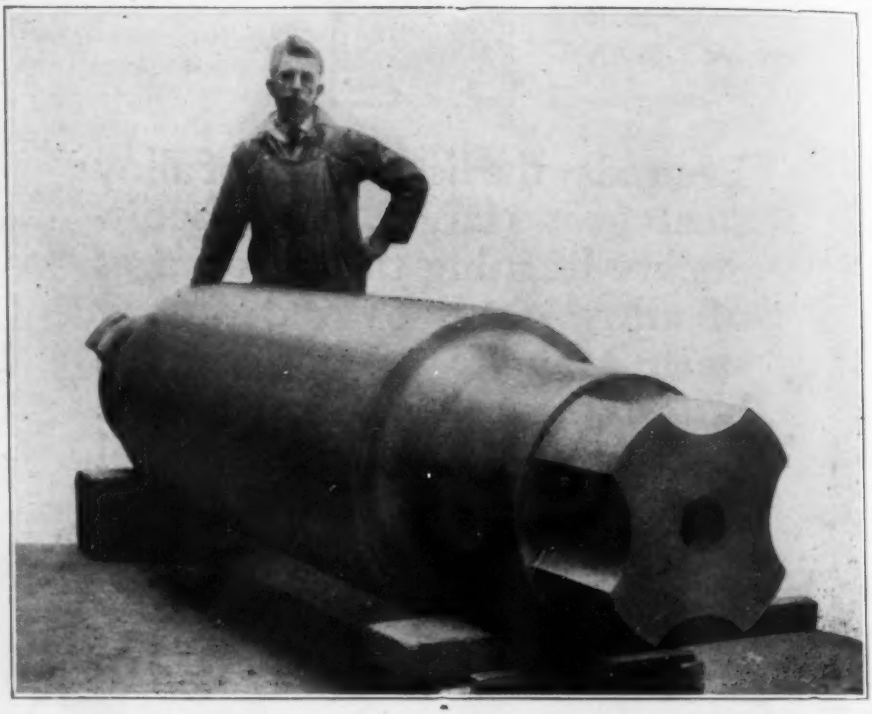

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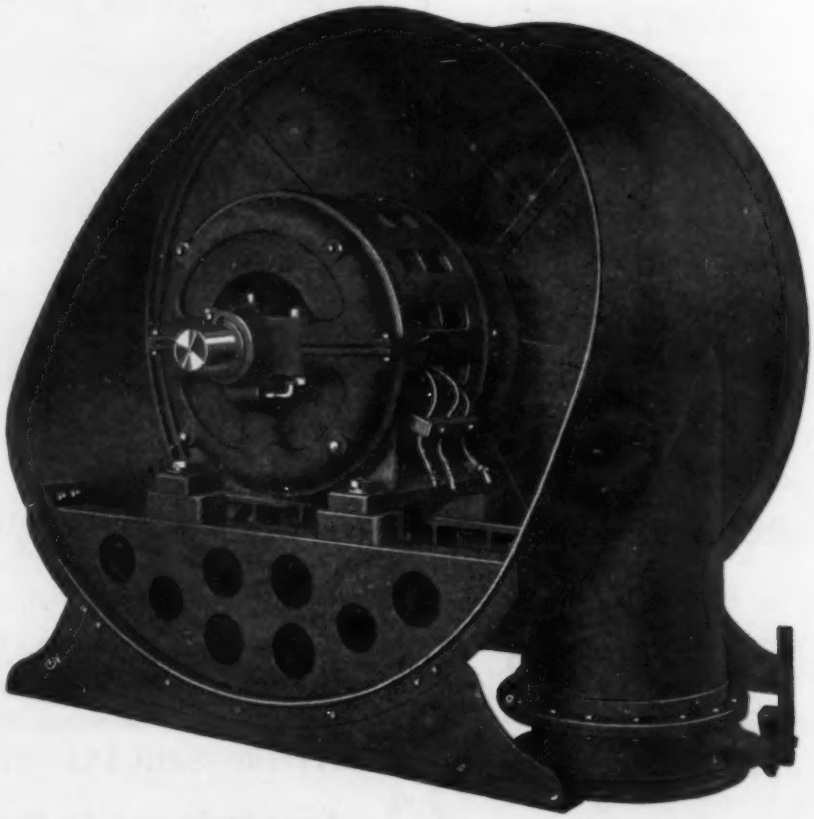

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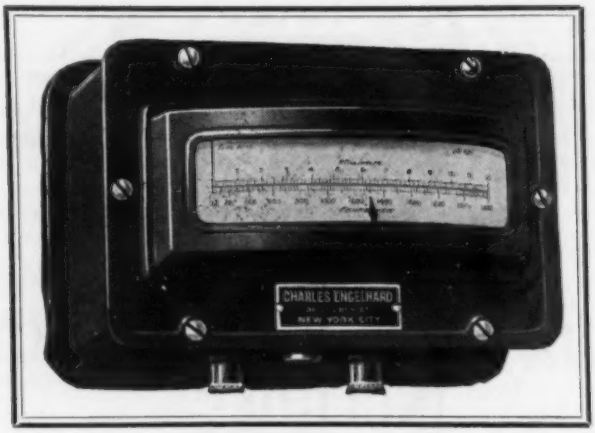

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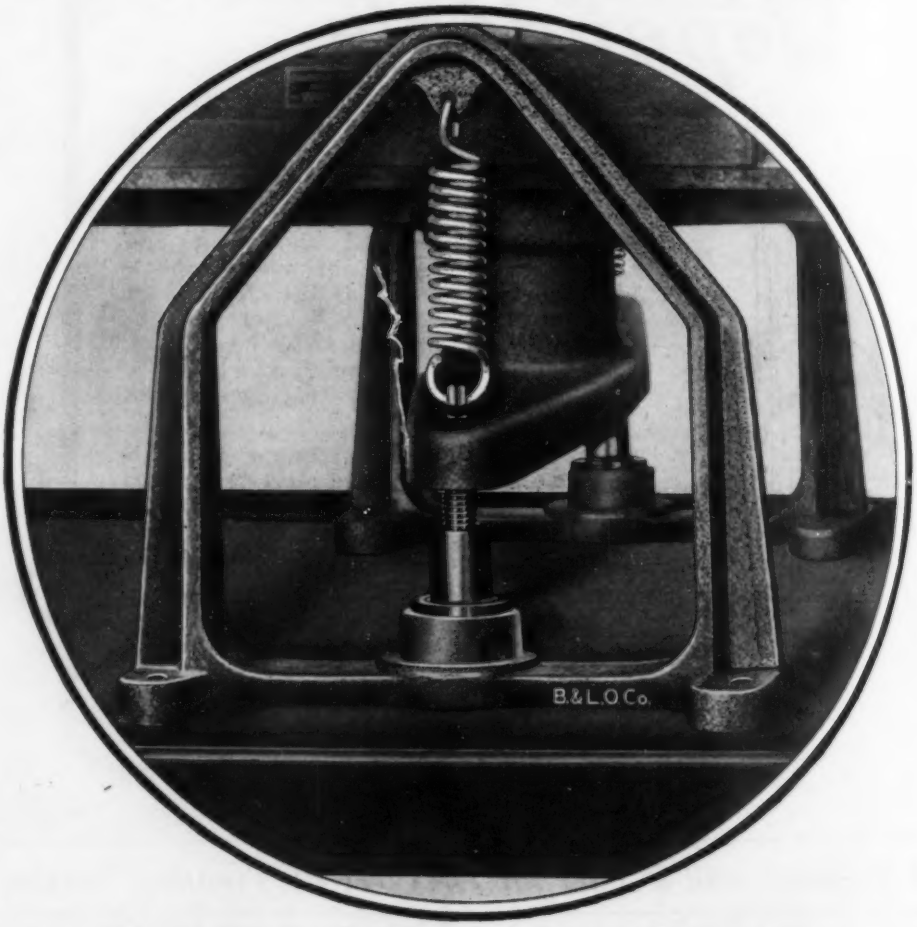

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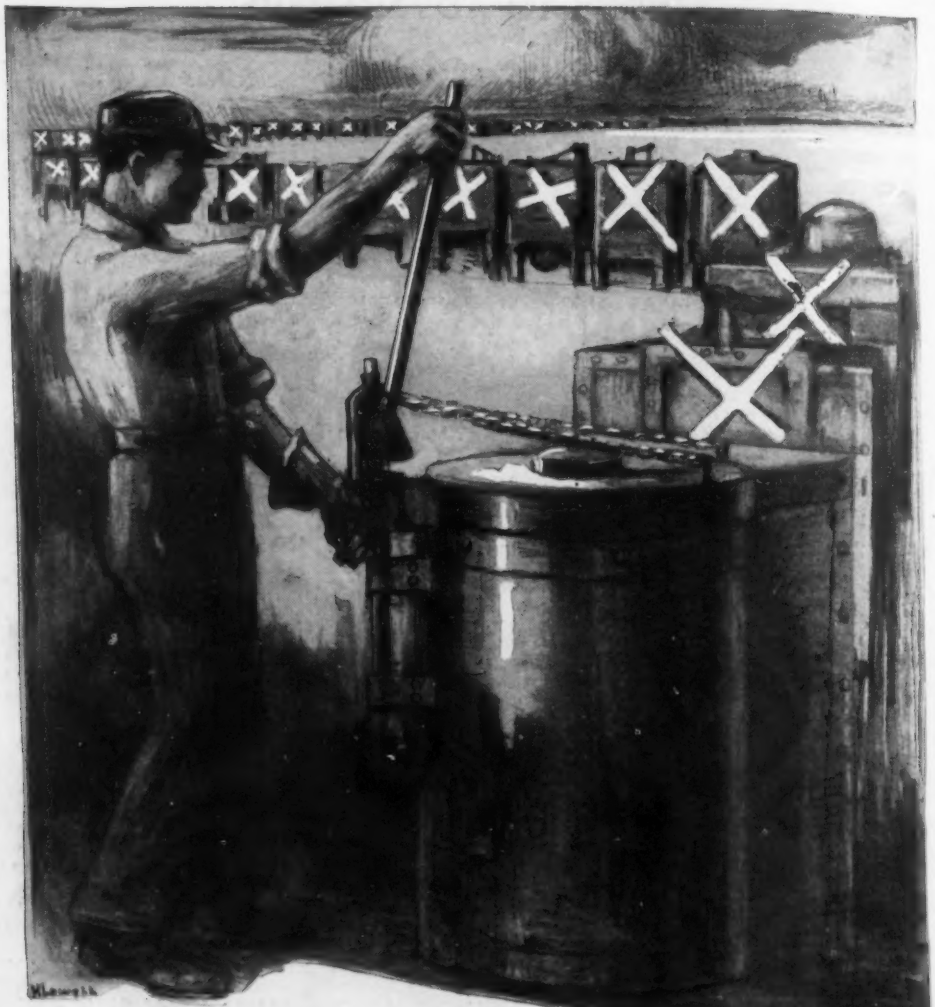

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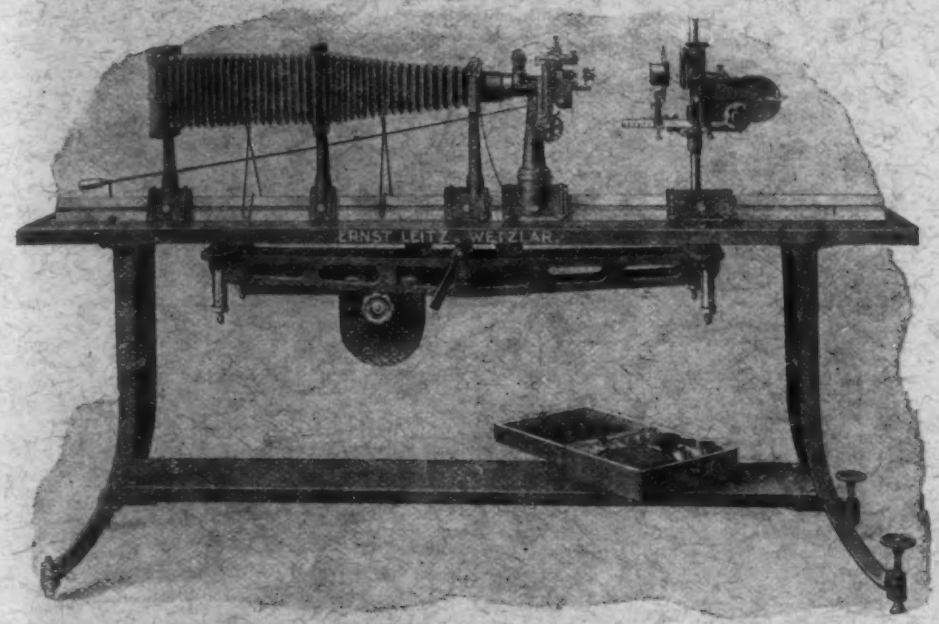

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